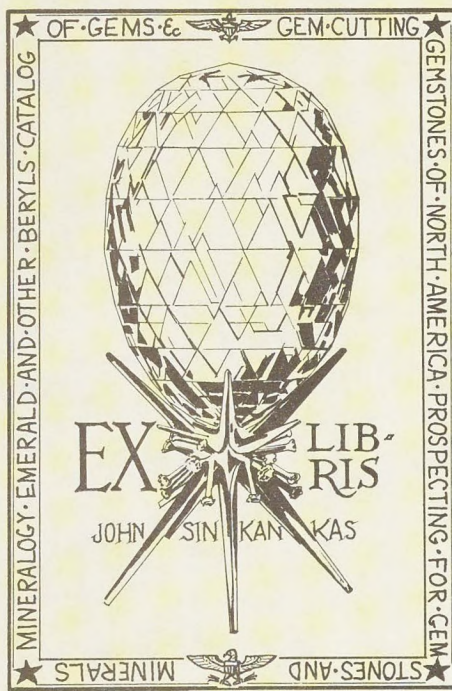
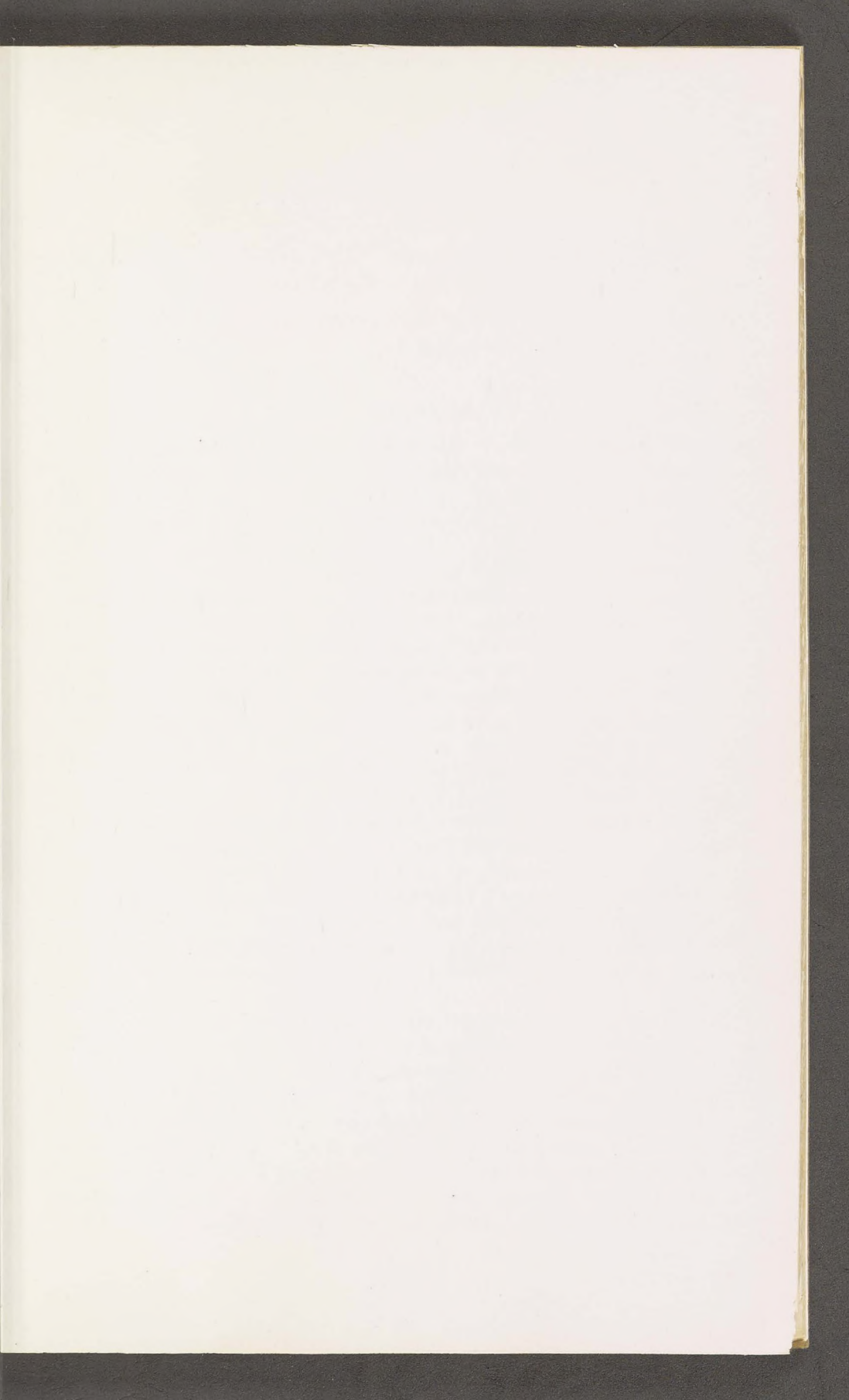


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USGS Bull 580, 1915

SALINES IN THE OWENS, SEARLES, AND PANAMINT  
BASINS, SOUTHEASTERN CALIFORNIA.

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By HOYT S. GALE.

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## INTRODUCTION.

The salt-incrusted valley floor commonly known as Searles Lake, in southeastern California, has lately come into prominence through the widespread interest in the search for an available source of potash in this country and the apparently promising prospects this locality affords of a considerable commercial production in the near future. The estimate that this deposit contains 4,000,000 tons of water-soluble potash salts, an estimate made with the first public announcement concerning it, in March, 1912, seems to have been amply confirmed by subsequent developments. That this amount of potash salts will actually be produced and placed on the market can not yet be considered assured, as, of course, the quantity that may be recovered depends on many factors, but so far as can be judged from the evidence available it seems that this deposit is the most promising immediate source of commercial potash in the United States.

The present account is a preliminary statement or review. It is not based on exhaustive field studies, but is rather the result of necessarily brief and hasty trips made through this and other parts of the Great Basin in pursuit of the general plan of investigations adopted in this work. These trips have resulted in a considerable collection of scattered data. The main features of the lake history and the deposition of the salines through the drying up of the lake waters are believed to be pretty clearly understood, and it is the present purpose to give a general account of these features.

This paper will therefore summarize the history of the waters in which these salts are believed to have been concentrated and through whose ultimate disappearance various saline and other deposits were laid down. Waters that formerly filled Owens Valley until they overflowed, flooding successively lower and lower basins, formed for a time a chain of large lakes in what is now the desert region of southeastern California. These flood waters passed from Owens Valley, the principal source of the water supply, through Indian Wells, Searles, and Panamint valleys, in each of which there was an exten-



sive lake. Finally the waters are believed to have overflowed also into Death Valley, and there the physiographic record has not yet been completely deciphered.

An attempt to understand the lake history of any one of these basins involves a consideration of all the rest, as each played its own independent part in the history of the whole system, and it appears that in no two of the basins is the present result even approximately the same. The extensive saline deposits at the bottom of the Searles Basin are a result of the overflow of waters from the shallow Owens Basin, but they were also influenced by the spreading out of these waters in Indian Wells Valley to form a broad, shallow lake in which the bulk of suspended sediment was probably laid down and beyond which the clarified and concentrating waters drained into the deeper and more isolated Searles Basin. The fact that the Searles Basin for a time overflowed into Panamint Valley and that the Panamint probably overflowed similarly into Death Valley evidently did not prevent the accumulation and deposition in the Searles Basin of an immense mass of solid crystalline salts and mother-liquor brine. It is the purpose to point out in the present paper the more salient distinguishing features and relations of these several basins and to suggest interpretations that may be placed on their influence in saline deposition. The general position and relations of these lakes and their drainage basins are shown on the index map forming Plate V, which also shows their relation to other known Quaternary lakes in this part of the Great Basin and the number and distribution of the present intermittent lakes or playas in which no record of Quaternary lakes has been discovered.

The following discussion is therefore divided into three main parts—first, Owens Lake and the Owens Basin; second, the Searles Basin and the saline deposits contained therein; and third, the ancient lake of the Panamint Valley, with a note as to its probable former connection with Death Valley:

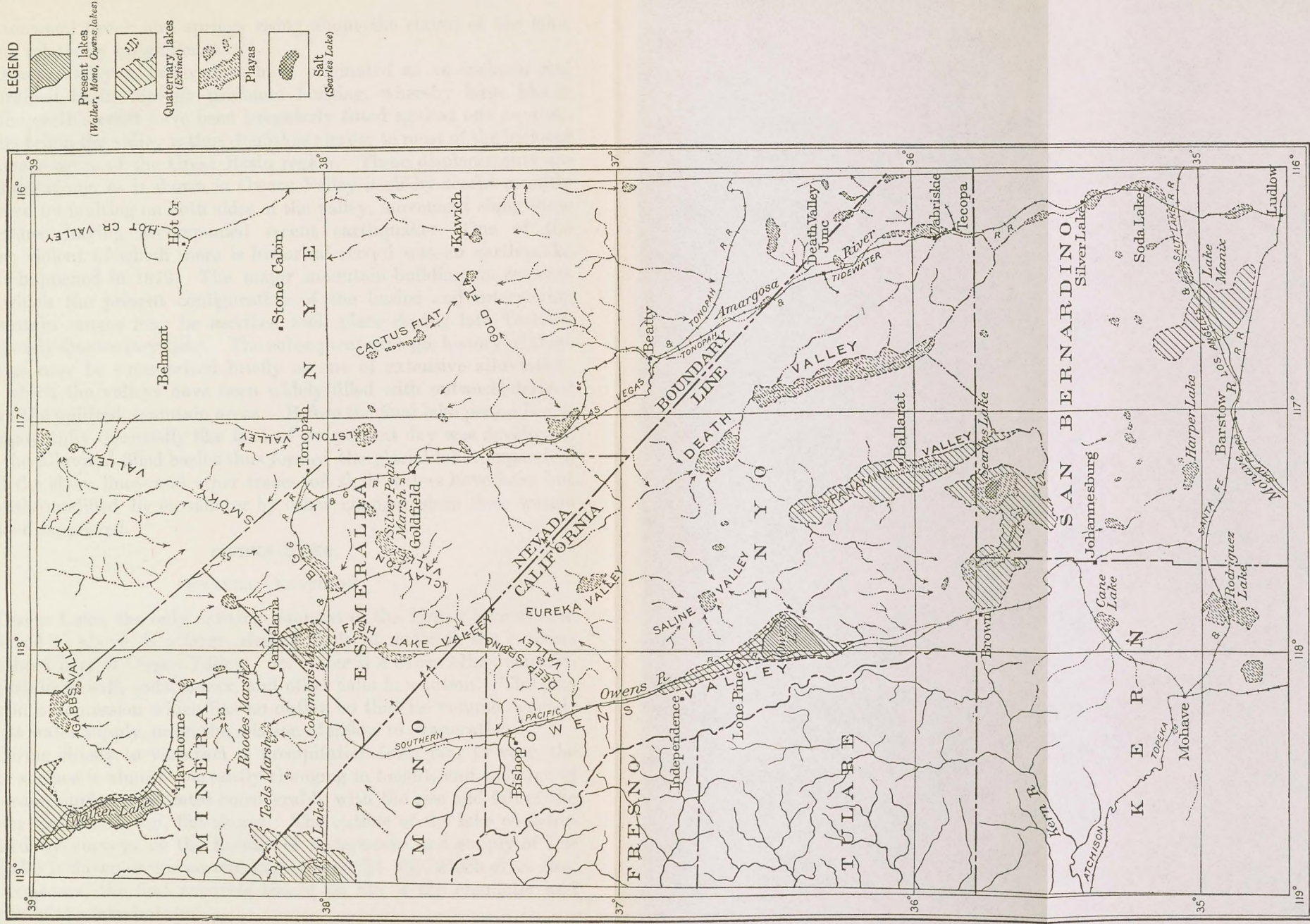
## THE OWENS BASIN.

### GENERAL FEATURES.

Owens Valley is a long, open, troughlike depression lying immediately west and at the very foot of the highest part of the Sierra Nevada, in Inyo County, southeastern California. It is an extensive basin, about 140 miles in length and 20 to 40 miles in width.

Owens River is one of the few larger perennial streams of the Great Basin region. Its water is derived mainly from the west side of its valley, in tributaries that rise among the snow-covered summits and more or less timbered flanks of the very highest part of the Sierra Nevada. This river constitutes the principal and in fact almost the only source of water supply to Owens Lake, other tributaries, such as

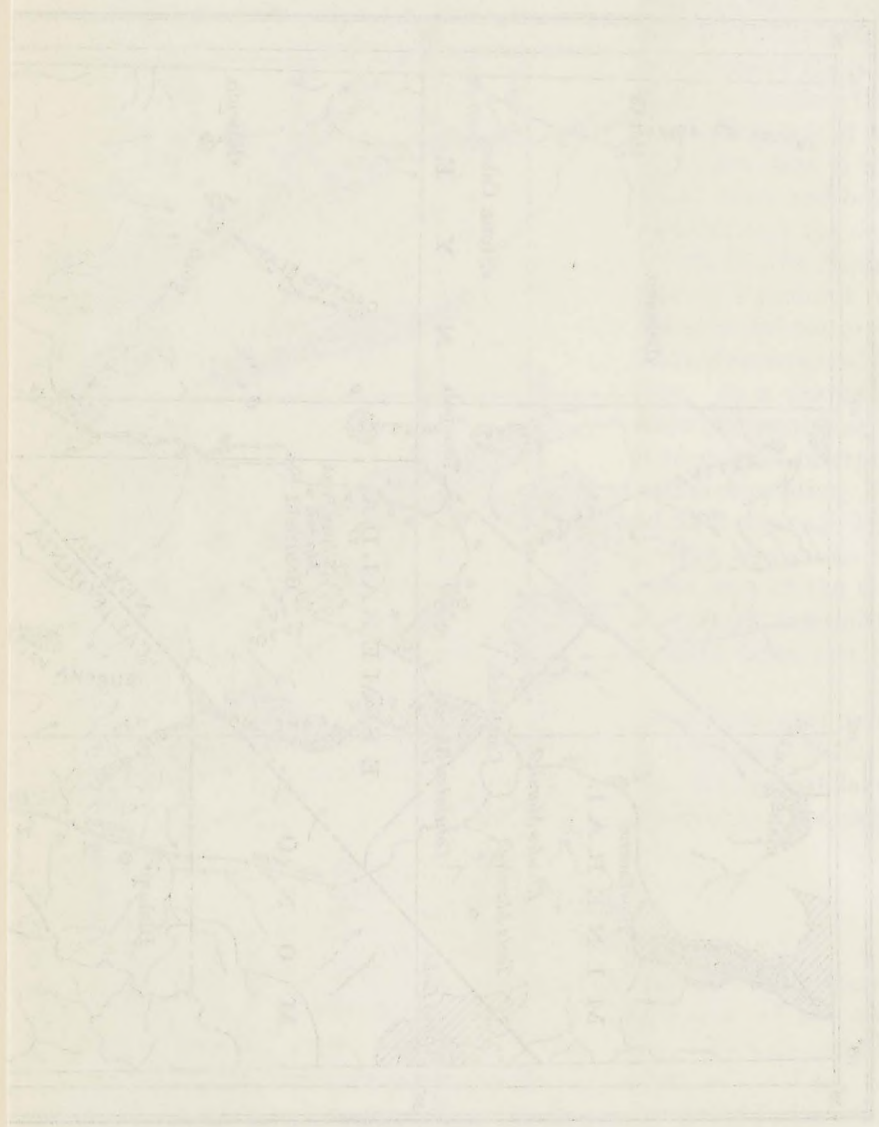




INDEX MAP SHOWING THE GENERAL POSITION OF THE OWENS-SEARLES-PANAMINT LAKE SYSTEM, CALIFORNIA.



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Cottonwood Creek and springs rising about the shores of the lake, being relatively insignificant.

Owens Valley is believed to have originated as an inclosed and undrained basin through profound faulting, whereby large blocks of the earth's crust have been irregularly tilted against one another. In its origin the valley is thus doubtless similar to most of the inclosed drainage areas of the Great Basin region. These displacements are still occurring, as is shown in Owens Valley itself by scarps recently formed by faulting on both sides of the valley, movement along these fractures having accompanied recent earthquakes. One of the most violent of which there is historical record was an earthquake that happened in 1872. The major mountain-building movements to which the present configuration of the basins and intervening mountain ranges may be ascribed took place during late Tertiary and early Quaternary time. The subsequent geologic history of these basins may be summarized briefly as one of extensive alluviation, by which the valleys have been widely filled with outwash derived from the uplifted mountain areas. Before the final lake period began a topography essentially like that of the present day was developed. In the alluvium-filled basins thus formed the glacial lakes expanded, and the shore lines and other traces of their waters have been but slightly modified by erosion or by other changes since their waters have disappeared.

### OWENS LAKE.

#### GENERAL FEATURES.

Owens Lake, the only existing remnant of the former lake system referred to above, is a large, shallow body of water in the extreme southern part of Owens Valley. Its water is a dense brine, containing common salt, soda, borax, and other salts in solution. The lake lies in a depression which has no outlet, so that its volume depends on its water supply, or on the relation of inflow to evaporation.

Owing chiefly to variation in precipitation from year to year, the lake surface is almost constantly changing in height, and the area of its water surface fluctuates considerably with the rise and fall of the water over the broad, flat shores. The outline of the lake as determined by surveys of the bureau of waterworks and supply of Los Angeles is shown on the accompanying map (Pl. VI), which gives also, by contours, the first accurate record on file of the character and depth of the lake bottom.

As determined by these surveys, the area of the water surface in February, 1913, was 62,267 acres, or 97.2 square miles, and the maximum depth of the water was 29.6 feet. The elevation of the water surface at this date was 3,577 feet.



## CHANGES OF WATER LEVEL.

The recorded changes of water level are shown in the following table, compiled in greater part from records previously published,<sup>1</sup> supplemented by data from the Los Angeles waterworks surveys and other sources.

*Elevation of water surface, Owens Lake, Cal.*

	Elevation of water surface.	Elevation above minimum recorded level.
	<i>Feet.</i>	<i>Feet.</i>
1872, "before irrigation was started in the Owens Valley".....	3,597.00	30.00
1876.....	<sup>a</sup> 3,586.40	19.40
1905, March 30.....	3,568.70	1.70
October.....	3,567.00	.....
1908, March 4.....	3,575.95	8.95
March 29.....	3,575.73	8.73
April 19.....	3,575.78	8.78
April 26.....	3,575.90	8.90
May 28.....	3,575.60	8.60
June 4.....	3,575.40	8.40
1909, May 1 (water reported higher than it had been for many years).		
1910, July 22.....	3,575.98	8.98
September 21.....	3,374.98	7.98
October 28.....	3,574.71	7.71
December 1.....	3,574.89	7.89
1911, January 5.....	3,575.29	8.29
February 8.....	3,576.11	9.11
July 12.....	3,577.35	10.35
July 28.....	3,578.03	11.03
November 1.....	3,577.35	10.35
November 5.....	3,577.50	10.50
December 3.....	3,577.60	10.60
1913, <sup>b</sup> February.....	3,577.00	10.00
July 3.....	3,572.90	5.90
August 7.....	3,572.30	5.30
September 4.....	3,572.00	5.00
October 13.....	3,571.47	4.47
November 9.....	3,571.42	4.42
December 4.....	3,571.40	4.40
December 28.....	3,571.46	4.46

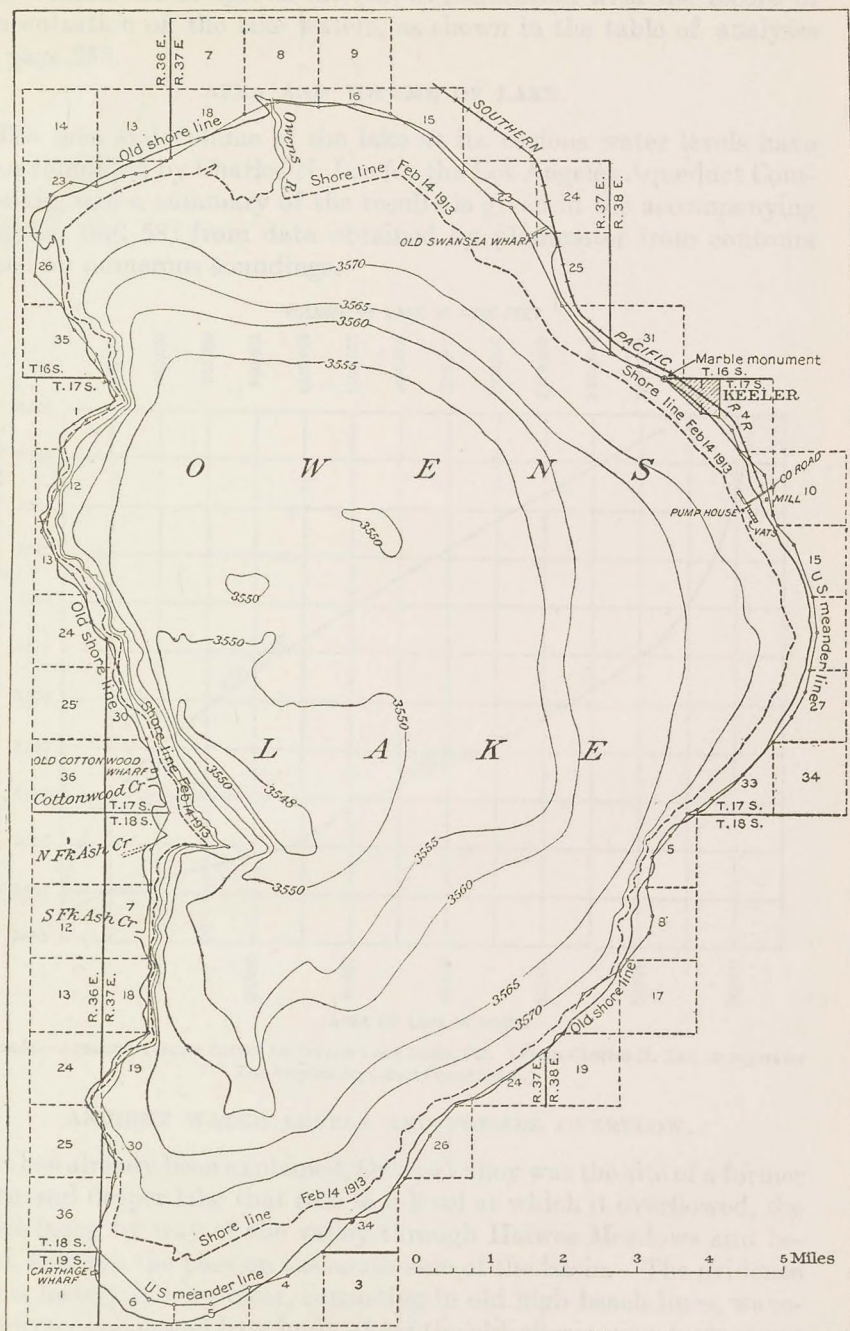
<sup>a</sup> Calculated from depth given by Loew.

<sup>b</sup> For these determinations the writer is indebted to Mr. William Mulholland, chief engineer bureau of waterworks and supply, Los Angeles, and to Mr. Charles H. Lee, hydraulic engineer, Los Angeles, who was in field charge of the observations and surveys, including the map (Pl. VI) and diagram (fig. 58).

Thus it appears that the fluctuations of the lake level within recent historic time have been considerable. It may be that this fluctuation should be ascribed in large part to the influence of irrigation, which, by increasing the surface for evaporation, has undoubtedly reduced the amount of water that would otherwise have annually reached the lake. However, the lake seems to have reached the recorded minimum in 1905, and since that time the amount of water diverted for irrigation has probably not decreased, yet the lake level has been considerably higher. It is of interest to note that the recorded maximum occurred in 1872 and, for comparison in this connection, that the highest water level recorded by measurements at Great Salt Lake was in 1873. The variations of lake level and of

<sup>1</sup> McGlashan, H. D., and Dean, H. J., Water resources of California, Part III: Stream measurements in the Great Basin and Pacific coast river basins: U. S. Geol. Survey Water-Supply Paper 300, p. 225, 1913.





MAP OF OWENS LAKE, CAL., SHOWING CONTOURS OF LAKE BOTTOM.

From surveys of Los Angeles Aqueduct Commission.





lake volume are of special interest in connection with the record of concentration of the lake waters, as shown in the table of analyses on page 258.

#### AREA AND VOLUME OF LAKE.

The area and volume of the lake at its various water levels have been computed by Charles H. Lee for the Los Angeles Aqueduct Commission, and a summary of the results is given in the accompanying diagram (fig. 58) from data obtained by planimeter from contours based on numerous soundings.

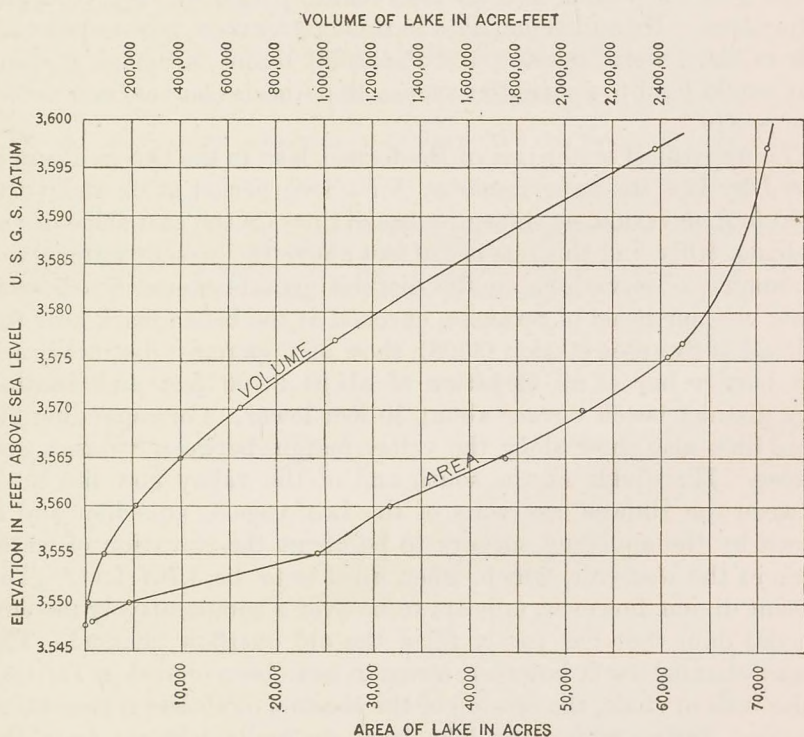


FIGURE 58.—Area and volume curves for Owens Lake basin, Cal. (From Charles H. Lee, in report for Los Angeles Aqueduct Commission.)

#### ANCIENT WATER LEVELS AND FORMER OVERFLOW.

As has already been explained, Owens Valley was the site of a former larger and deeper lake that rose to a level at which it overflowed, the outlet being by way of the valley through Haiwee Meadows and beyond, through the pass on the south side of the basin. The evidence of this history is very clear, consisting in old high beach lines, wave-cut terraces and sand bars built along the old shores, now high above the lake water level, and the distinctly marked channel of a long-continued overflow by which the surplus waters passed on to the lower basins south and southeast of Owens Valley. The area of the



former lake in Owens Valley at the level of its last overflow (3,760 feet) is computed to have been about 240 square miles.

The flooding of these basins is supposed to have been coincident with the general extension of glaciation in the higher adjoining mountain ranges and is consequently referred to the glacial epoch of the Quaternary period. It is generally agreed that there were at least two periods of ice advance in this part of the country during the glacial epoch, and for Lakes Lahontan and Bonneville it is thought that there may have been two corresponding stages of maximum flooding in the basins and an intervening period of very complete desiccation. No additional data in this matter seem now to be available in the Owens, Searles, and Panamint basins, although nothing that would tend to contradict such a hypothesis has yet been noted. (See p. 319.)

The uppermost water line of the former lake in the Owens Basin is stated by Lee<sup>1</sup> to have remained for a long period at or about the 3,790-foot elevation, as shown by beach lines on the east slope of the Alabama Hills, and this line is 220 feet above the present water level. Barometric observations on the distinct gravel-covered beach remnants just northeast of Swansea, checked at the bench mark near the railroad at Swansea station (3608), show an uppermost distinct beach and barrier bar at an elevation of about 3,700 feet and another very distinct beach terrace about 30 feet lower. Corresponding old shore lines also show along the valley margin between Swansea and Keeler. The divide at the south end of the valley now lies in or between the Haiwee reservoirs of the Los Angeles aqueduct and is shown by the aqueduct surveys to be about the elevation of water level in the reservoir, which when filled is to be 3,764 feet.<sup>2</sup> The present divide, however, appears to be over a comparatively modern alluvial dam that has partly filled the old overflow channel. The former channel itself, however, seems to have been eroded in Tertiary white tuffs or shale, the erosion of the channel doubtless representing a period during which the lake level gradually lowered from the 3,790-foot level to 3,760 feet, the water finally standing 190 feet above the present lake level, before it began to subside by evaporation alone within its inclosed basin. It is possible—in fact, it seems quite probable—that recent fault disturbances to which the valley has been subjected may have locally offset these former shore markings, and the elevations obtained from them may therefore be subject to some latitude of interpretation.

<sup>1</sup> Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 294, p. 73, 1912.

<sup>2</sup> Bur. Los Angeles Aqueduct Seventh Ann. Rept., November, 1908.



## COMPOSITION OF WATER.

The composition of the water of Owens Lake is recorded in a series of analyses that have been made from time to time, beginning with one by J. Arthur Phillips from a sample collected in January, 1866. Most of these have been published before,<sup>1</sup> but one analysis and several other late determinations are added in the following list. These analyses agree fairly well. As would be expected, the principal variation is in the concentration of the water, which is naturally the result of or is concomitant with the fluctuating volume of the lake already referred to.

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<sup>1</sup> Phillips, J. A., The alkaline and boracic lakes of California: Pop. Sci. Review, vol. 16 (2d ser., vol. 1), pp. 153-164, London, 1877.

Loew, Oscar, The Owens Lake, Inyo County, Cal.: U. S. Geol. Surveys W. 100th Mer. Ann. Rept. for 1876, p. 190.

Chatard, T. M., Natural soda, its occurrence and utilization: U. S. Geol. Survey Bull. 60, pp. 27-101, 1890.

Bailey, G. E., Saline deposits of California: California State Min. Bur. Bull. 24, p. 93, 1902.

Lee, W. T., Geology and water resources of Owens Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 181, pp. 21-22, 1906.

Van Winkle, Walton, and Eaton, F. M., The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, p. 122, 1910.

Clarke, F. W., The data of geochemistry, 2d ed.: U. S. Geol. Survey Bull. 491, p. 58, 1911.

Waring, G. A., Springs of California: U. S. Geol. Survey Water-Supply Paper 338 (in press).



*Composition of salts dissolved in water of Owens Lake, Cal.*

[Calculated to percentage of anhydrous residue.]

	1	2	3	4	5	6	7	8	9	10
Date of collection.....	Jan., 1866	Oct., 1876	Mar., 1882	Sept., 1886	Quoted in 1902	July, 1904	Aug., 1905	May, 1912	Oct., 1912	Feb., 1914
Analyst.....	Phillips.	Loew.	Lunge.	Chataud.	Unknown.	Wrinkle.	Stone & Eaton.	Bailey.	Hicks.	Hicks.
Specific gravity.....	1.076	1.051	1.063	1.062 at 25° C.	.....	1.186	1.195	1.0845	1.0977 at 20° C. <sup>a</sup>	1.0972 at 20° C.
Cl.....	25.12	22.20	25.80	25.67	25.75	.....	24.82	.....	25.56	.....
SO <sub>4</sub> .....	10.06	15.47	9.97	9.95	10.00	.....	9.93	.....	9.96	.....
CO <sub>3</sub> .....	23.22	21.73	23.60	23.51	18.34	.....	24.55	.....	22.18	.....
PO <sub>4</sub> .....	23	.....	.....	.....	.....	.....	.11	.....	.....	.....
B <sub>2</sub> O <sub>3</sub> .....	.....	.....	.....	.....	.50	.....	.14	.....	1.92	.....
NaO.....	.....	.....	.....	.48	.....	.....	.45	.....	.....	.....
Na <sub>2</sub> O.....	38.55	35.78	.....	37.83	42.79	.....	38.09	.....	38.07	.....
K.....	2.05	4.55	40.63	2.18	2.20	.....	1.62	.....	2.10	.....
Li.....	.....	.....	.....	.....	.....	.....	.03	.....	.....	.....
Ca.....	.....	.....	.....	.02	.....	.....	.02	.....	.....	.....
Mg.....	.....	.....	.....	.01	.....	.....	.01	.....	.....	.....
SiO <sub>2</sub> .....	.....	.....	.....	.29	.29	.....	.14	.....	.21	.....
Al <sub>2</sub> O <sub>3</sub> .....	.77	.28	.....	.04	.13	.....	.04	.....	.....	.....
FeO.....	.....	.....	.....	.02	.....	.....	.....	.....	.....	.....
As <sub>2</sub> O <sub>3</sub> .....	.....	.....	.....	.....	.....	.....	.05	.....	.....	.....
Total anhydrous salts, percentage of original sample.....	8.74	6.05	6.88	7.27	.....	.....	21.37	9.59	10.95	10.95

<sup>a</sup> The specific gravity given is that of the solution at the temperature of 21° C. referred to water at 20° C.



1. Analysis by J. Arthur Phillips quoted in his article already cited. As there stated in grains per imperial gallon, it includes 16.94 grains of organic matter, which has been eliminated in the recalculation to anhydrous residue here given. The original statement of this analysis in the reference here given differs from the reference which has been generally quoted from Bulletin 24 of the California State Mining Bureau, page 95, although apparently referring to the same analysis.

2. By Oscar Loew, loc. cit.

3. By George Lunge, one of two analyses quoted. Sulphuric acid and alkali, vol. 2, pt. 1, 1890.

4. By T. M. Chatard, loc. cit.

5. Quoted by Gilbert Bailey, loc. cit.; no date or name of analyst given.

6. Determinations by Noah Wrinkle, quoted by W. T. Lee, loc. cit. The lake is reported to have been 16 feet lower at this time than it was in 1894.

7. Recalculation of analysis as quoted by F. W. Clarke, loc. cit.

8. Sample collected by F. L. Young, superintendent of Inyo Development Co., Keeler, Cal., from sump at end of the company's pipe line, where water is said to have been 9 feet deep. Partial analysis by R. K. Bailey in Geological Survey laboratory at Washington.

9. Sample collected by Hoyt S. Gale at same place as sample 8, below water surface. Analyzed by W. B. Hicks in Geological Survey laboratory at Washington.

10. Sample collected by F. L. Young at same place as sample 8. Partial analysis by W. B. Hicks in Geological Survey laboratory at Washington.

In all these analyses bicarbonate in the original solution is reduced to carbonate in the anhydrous residue and is so expressed. For the sample of October 23, 1912, analyzed by W. B. Hicks, the bicarbonate radicle ( $\text{HCO}_3$ ) amounted to 4,790 parts per million by weight.

One notable feature brought out by comparison of these results is the divergence in boric acid determinations. Mr. Hicks states that his determinations of boric acid have been carefully checked by various methods and are believed to be correct. Where boric acid has not been determined in the other analyses, it was probably included in the expression of results as carbonate. It is also to be noted that the sample collected August 21, 1905, was of the maximum recorded density, almost exactly double that of the present day, and that the lake was reported to have been practically constant at that level and density for three years previous to that time.

On the assumption that the lake level in October, 1912, was about 3,577 feet at the time when the last recorded sample for fairly complete analysis was taken, a volume of approximately 1,000,000 acre-feet of water is indicated. A calculation from the analysis quoted shows that the lake waters contain in round numbers as follows:

*Approximate total content of chlorine, sodium, etc., in the water of Owens Lake.*

	Short tons.
Chlorine .....	40, 000, 000
Sodium .....	60, 000, 000
Potassium .....	3, 360, 000
Anhydrous boric acid ( $\text{B}_2\text{O}_3$ ) .....	3, 070, 000
Total anhydrous salts .....	160, 000, 000



These figures are considerably in excess of the estimates made by Loew,<sup>1</sup> who calculated 5,000,000 tons of sulphate of potassa; but Loew's figures for volume were very moderate even for the data which he then had, and the present estimates have the advantage of much more exact volume computations.

The estimate that over 3,000,000 tons of potassium is dissolved in the Owens Lake water is doubtless not far from correct, but this figure is not intended for direct comparison with the estimates of available potash given for the Searles Lake deposits. The percentage of potash in the Owens Lake water is so much lower than that in the Searles brine that there is much doubt if the Owens Lake water may ever be used for the extraction of this substance, unless it is obtained as a by-product of some other process, or unless the water shall reach a greater natural concentration. There is, of course, a vastly greater amount of potassium in the water-soluble salts in the Searles basin than that included in the 4,000,000-ton estimate.

The anhydrous salts of Owens Lake, if entirely freed of water and deposited in the present lake bottom, would cover an area of about 25 square miles, as computed from the table on page 255, and have a thickness in the deepest part of the basin of 5 or 6 feet. Of course no such complete evaporation of the water would occur naturally, and both water of crystallization and the dense mother liquor naturally retained with such a deposit would increase the bulk very considerably over the figures given above. Perhaps the water so retained would constitute more than two-thirds of such a deposit, and if so its area would be at least 40 square miles and its greatest depth over 10 feet.

#### OWENS RIVER.

##### SOURCE OF THE SALTS.

The salts now contained in solution in Owens Lake were undoubtedly derived by the slow accumulation and concentration of the river waters entering the basin. As this water supply is and has been continuous, and as there has not been any overflow or outlet except by evaporation for a very long time, it is clear that salts naturally dissolved in the river waters, though in very dilute solution, have eventually concentrated into the dense brine which is now found in the lake. Some figures are given further on which will not only represent the rate at which the waters and their contained salts are accumulating but which may also afford a basis for estimating the length of the present period of salts accumulation.

##### VOLUME.

The volume of Owens River has been very carefully measured—in fact, the records are more than ordinarily complete owing to the careful investigations that have been conducted preliminary to the

<sup>1</sup> U. S. Geol. Surveys W. 100th Mer. Ann. Rept. for 1876, p. 190.



diversion of its waters for the Los Angeles municipal water supply. Discharge measurements at several stations along the river have been taken for a period of many years. Those available for the lowest station, opposite Lone Pine, some 12 miles above the mouth, are as follows:

*Total discharge of Owens River near Lone Pine, Cal., about 12 miles above the mouth, 1909-1912.*

	Acre-feet.
1909.....	358, 100
1910.....	249, 900
1911.....	416, 000
1912.....	194, 900
Average (4 years).....	304, 725

From these figures the present annual discharge may be assumed to average about 300,000 acre-feet, although it is to be noted that the variation is large. The flow for 1911 was more than double that for 1912; and it is stated that the total flow during 1906 or 1907, which were the wettest years since 1903, was nearly double that of the driest year of the same period.

#### COMPOSITION OF DISSOLVED SALTS.

The dissolved mineral salts in Owens River water have also been very carefully studied. The content of saline matter in the river water varies with the volume of the river. It is generally true that the periods of greater flow show more dilute water, and the opposite is believed to be true also, a general relation which is borne out by the two very complete yearly records given herewith, as well as in a more general way by the details of the monthly records. A report has been published giving an estimate of the salt content and the total weight of dissolved salts in Owens River water at Charlies Butte from November, 1906, to November, 1907, inclusive, a period of 13 months.<sup>1</sup> This estimate is based on determinations made on 40 or more samples collected at different times throughout the year. By evaluation of the different salt determinations according to the total flow for the period they are intended to represent, an average dissolved salt content in the river water for that year of 278 parts per million was obtained.

Analyses of a very complete set of samples of water collected from Owens River at the same station are also summarized<sup>2</sup> in a mean of thirty-six 10-day composite samples taken December 31, 1907; to December 31, 1908, which gives the mean salinity of the riverwater for that period as 339 parts per million. This shows a greater concentration of saline matter in the water in 1908 than in 1907, but discharge data

<sup>1</sup> Los Angeles Aqueduct Third Ann. Rept., pp. 113-114, 1907.

<sup>2</sup> Van Winkle, Walton, and Eaton, F. M.; The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, p. 121, 1910.



show that the volume of river water during 1908 was only a little more than half that of the preceding year. To a certain extent, therefore, these factors compensate one another, so that the yield of saline material each year may be considerably more constant than might be at first assumed from a mere comparison of volumes of flow.

The mean composition of the Owens River water for one year is shown in the following average:

*Average saline composition of Owens River water at Charlies Butte, December 31, 1907, to December 31, 1908.*

[Walton Van Winkle and F. M. Eaton, analysts. Percentage of anhydrous residue.]	
SiO <sub>2</sub> .....	12.37
Fe <sub>2</sub> O <sub>3</sub> .....	.09
Ca.....	8.92
Mg.....	3.45
Na+K.....	19.83
CO <sub>3</sub> .....	29.84
SO <sub>4</sub> .....	15.53
NO <sub>3</sub> .....	.48
Cl.....	9.49
	<hr/> 100.00

Total solids, 339 parts per million.

As usual in this method of expressing analytical results, the bicarbonate of the original river water is reduced to the equivalent carbonate in the expression as the anhydrous residue.

Estimates of the total amounts of the various saline constituents contributed to Owens Lake by Owens River are not particularly significant in the present study, for the salts dissolved in the water of the stream, where they exist usually in very dilute solution, undergo many changes on mixing with the standing and more strongly concentrated solution in the lake. Bicarbonate from the river water is partly changed to carbonate, especially in the presence of calcium and magnesium, with which some of it is precipitated in the form of less soluble salts and is included in the silt on the bottom. Silica also is partly deposited. Under certain conditions sulphate is partly reduced to sulphide by organic matter, and this may be taking place to some extent in the muds on the lake bottom, although in the main the loss of sulphate from the solution is believed to be due to the formation of less soluble minerals. Nitrates are relatively unstable when exposed, being peculiarly subject to the action of organic agencies. Potassium has long been known to be taken up and removed from solution by muds, soils, or clays, which have a very important power of absorption for that element. It is generally believed that potassium progressively disappears from the water throughout the silt-laden course of the stream and that this action continues after the solution enters the standing water in the lake. This very important



factor with reference to the occurrence of soluble potash salts as a product of such saline concentrations will be given fuller consideration later. (See pp. 321-323.) As a result of these changes the salts that accumulate in the lake water are not by any means the sum of the constituents brought in by the tributaries.

Two radicles, however, seem more likely to accumulate and remain in solution under the conditions above described, namely, sodium and chlorine, and the annual amount of these two substances brought into Owens Lake by Owens River may be estimated from the data quoted for the year 1908. The total discharge for 1908 at Charlies Butte, the station where the samples for analysis were taken, was 218,000 acre-feet. From this it is calculated that at least 17,000 tons of sodium<sup>1</sup> and 9,500 tons of chlorine were contributed that year to Owens Lake by Owens River. These figures represent the soluble mineral content of the water that passed Charlies Butte that year, and not necessarily the total mineral content of the river as it enters the lake. Unfortunately no such comprehensive data are available for a lower station, and it is not known just what relation the figures given would bear to the discharge of salinity of the lower river. Another factor undoubtedly merits careful consideration in the refinement of such calculations as are here given, namely, the influence that modern irrigation may have had on the salinity of the river flow or on the composition of the lake. It is likely that the influence of this factor would be difficult to determine exactly.

If estimates of this sort are to be carried out with a greater degree of refinement, it would doubtless be better to use figures for average discharge over a number of years for computing the amount of denudation, because the variation in discharge is greater than the variation in content of dissolved salts.

#### GEOLOGIC AGE OF OWENS LAKE.

The idea of calculating the age of a landlocked lake from an estimated annual rate of accumulation of its dissolved saline constituents is not new.<sup>2</sup> The results thus obtained can not be considered wholly satisfactory, for in spite of certain factors that may be quantitatively measured there must always remain other essential factors which can not be exactly determined and which must rest largely on assumption. The total volume of Owens Lake, its composition, and the quantity and composition of its inflowing waters are now known with a considerable degree of exactness. It has already been stated that the total chlorine content of the lake waters is approximately

<sup>1</sup>Sodium is assumed to be 17 per cent of the anhydrous residue in the analysis, in which sodium and potassium are reported together.

<sup>2</sup>Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 255-258, 1890. Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, pp. 226-227, 1885.



40,000,000 short tons. If the annual contribution of chlorine from the flow of Owens River has been 9,500 tons, it has required 4,200 years for the accumulation of this total amount of chlorine.

By similar reasoning the total sodium content of the lake waters is 60,000,000 tons. If the annual contribution of sodium from inflowing waters is 17,000 tons, this represents some 3,500 years of accumulation.

If such computations were worthy of even greater degree of refinement allowance might be made for the total quantity of the elements that may have been contained in the lake waters when the lake last ceased to overflow. In a rough way, however, it may be assumed that the figures given represent the time occupied by the last stage of the lake history—namely, that since water last ceased to overflow—during which the waters have by accumulation and evaporation concentrated the more stable dissolved constituents at a fairly definite annual rate. Although when the lake expanded to the maximum of two and one-half times its present evaporating surface the volume of flow in the river was doubtless at least two and one-half times its present flow, there probably was then a diminution in the relative proportion of dissolved salts in the waters contributed.

#### SUMMARY.

In the foregoing pages the character of the Owens Lake basin and the composition of its river and lake waters have been discussed. During an undetermined though probably a very considerable period Owens Lake overflowed. One period of overflow is probably to be correlated in time with the general expansion of other inland lakes in the Great Basin, such as Lakes Lahontan, Bonneville, and Mono, with which, however, it had no direct connection. While the overflow continued the waters in the lake were comparatively fresh, being derived from melting snows and ice fields, chiefly of the Sierra Nevada. Saline material derived from rock decomposition within the tributary drainage area was carried forward with the more abundant water supply in the same way that it is carried in Owens River water to-day. Since the final cessation of the overflow from this basin, brought about perhaps by a gradually diminishing water supply, concentration by evaporation of the river waters has been going on. The result has been the accumulation in Owens Lake of a great quantity of soluble saline material. The length of time it has taken to accomplish this accumulation is in very general terms about 4,000 years, or possibly considerably less. This period also includes the final desiccation and subsequent alluviation in the other lake basins in the Owens-Searles-Panamint drainage system. Consideration of the further evidence afforded in these other basins follows.



## SEARLES LAKE.

## GENERAL FEATURES AND HISTORY.

Searles Lake or Marsh, also known as Slate Range Marsh and Bórax Flat, is a dry lake basin, superficially much like many other desert basins of the western arid region of the United States. These names, as generally applied, refer to the broad, flat salt-incrusted surface in the center of the desert basin, although, except as it is intermittently flooded by shallow waters, the region strictly does not contain a lake at all. The basin in which Searles Lake is situated seems to have no generally accepted name but will here be designated the Searles Basin. It is a broad, roughly circular valley or depression 8 to 10 miles from east to west and 20 to 25 miles from north to south, bordered by the abruptly rising slopes of the surrounding mountain ranges. This basin lies between the Argus Range on the west or northwest and the Slate Range on the east, the latter a narrow rocky wall which divides it from the larger and deeper depression of the Panamint Valley. The camp at the old soda works in the Searles Basin is in the northwest corner of the main desert flat, some 25 miles by road from Searles post office, formerly Garden Station, an old stage stop of the overland route through this part of the desert country. Garden Station is now only about a mile east of the branch line of the Southern Pacific Railroad. Searles Lake has been reached by the regular stage that runs from Johannesburg via Garden Station, or Searles, to Searles Lake, and thence on to Ballarat and Skidoo, and passenger traffic doubtless still goes this way, although the branch railroad is now completed, connecting the Searles basin with the Southern Pacific main line.

The Searles Basin was, during a part of the glacial epoch, occupied by at least one deep lake whose traces are still so distinct as to be indisputable. While the waters stood at their highest position the Searles Basin was flooded to a depth of 635 to 640 feet above the level of the present valley bottom and the lake extended back through the Salt Wells Valley to join with a broad, shallow lake that flooded the greater part of the Indian Wells Valley. With the lowering of the water level less than 75 feet the divide in the volcanic peaks between Indian Wells Valley and Salt Wells Valley became an actual division between two distinct water bodies, and for a time here also there was a period of overflow from Indian Wells Valley to the lower waters in the Searles Basin in the same way that Owens Valley overflowed and spilled its waters into Indian Wells Lake. These are facts attested by the records of the ancient shore lines and water channels.

Horizontal beaches and shore markings over the more rocky portions of the marginal slopes show with great distinctness around the



present valley, being preserved in certain localities much more clearly than in others and having been practically removed in still other parts by recent erosion. The old shore lines are more or less marked with deposits of calcareous tufa, in some places amounting to very considerable masses, resembling the tufa deposits of the Lahontan, Mono, and Bonneville basins, described by Russell<sup>1</sup> and Gilbert.<sup>2</sup>

The absolute elevation of a former temporary water line is very difficult to determine. Hence observations on the elevation of these shore lines can not be depended on within at least several feet. A number of spirit-level bench marks have been established by recent surveys for the more accurate determination of the height of the old shore lines. Although these figures show some slight variation, it may be no more than the latitude which should be allowed in the identification of the actual water level on the beach. These readings are as follows:

*Elevation on uppermost shore level of the ancient lake in Searles Basin.*

Permanent bench mark on upper shore in canyon $2\frac{1}{2}$ miles north-west of old soda works and southwest of the tanks.....	Feet. 2,255
Permanent bench mark in first large canyon on west side of the basin north of old soda works (not definitely known that this represents the actual shore level).....	2,245
Temporary bench mark on highest bench on east side of basin, 7 miles east of the old soda works.....	2,262
Permanent bench mark in old channel of overflow at south end of basin (elevation of highest point in pass 2,264 feet).....	2,262

The determined elevation of the lowest part of the present salt flat in the main Searles Basin being 1,617.6 feet, the maximum height of the former lake above the salt surface, as indicated by these readings, was 635 to 640 feet.

In this connection a barometric record of the benches on the slope of the Slate Range in the main basin east of the old soda works is of interest as showing the more permanent water levels marked during the recession of the waters.

<sup>1</sup> Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, 1885.

<sup>2</sup> Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.



*Elevation of benches on slope of Slate Range.*

	Elevation by baro- metric reading.	Height above salt flat.
	<i>Feet.</i>	<i>Feet.</i>
Edge of salt flat, northeast corner (above or beyond this is a rise over a deep sandy alluvial slope).....	1,625	.....
A clear, boulder-strewn shore terrace with scattered tufa.....	1,850-1,910	285
An indistinct beach line.....	1,965	340
Foot of distinct basalt boulder wave-cut cliff. (The first distinct tufa-marked shore northwest of the soda works is at 2,035 feet, barometric reading).....	2,000	375
Top of a second distinct wave-cut cliff (10 feet or more high), assumed to be a beach.....	2,050	425
Top of next minor wave-cut cliff, a fairly distinct terrace, assumed to be part of an old beach.....	2,080	455
Top of wave-cut cliff with very narrow beach back of it.....	2,115	490
Narrow bench.....	2,130	505
Narrow but distinct bench.....	2,160	535
Very minor bench.....	2,170	545
Top of small bench.....	2,180	555
Upper edge of highest and most distinct beach, at base of a marked wave-cut rock cliff 30 feet or more above and beyond this point. (The cliff may be the point determined by the topographic party, temporary bench mark 2,262 feet).....	2,240	615

As indicated by this record, the topmost distinct water line is the most deeply cut, and as its elevation corresponds with the elevation of the outlet channel, this agrees well with the conception that the lake may have had a comparatively long period of overflow. The overflow undoubtedly ceased abruptly with the cutting off of the main water supply from the Owens Valley, if not before, and from that time on evaporation must have proceeded almost uninterrupted until conditions somewhat like those of the present were established. Several of the lower water marks, such as those of the 375-foot and 415-foot levels, are very distinct, but no special significance can yet be attached to them. The outline of the 375-foot level is practically the 2,000-foot contour.

Calcareous tufa forms conspicuous deposits along several of the more distinct shore lines and coats most of the minor shore benches. It is evident that these deposits are built up from lime precipitated from the entering ground or surface waters, presumably deposited as these solutions became exposed to the air and mingled with the stronger standing waters of the lake. The Pinnacles, conspicuous tufa crags rising to a height of 100 feet or more at the southwest corner of the basin, were probably formed in a similar manner, perhaps by waters rising from springs along a fault zone at a time when the lake stood at one of its lower levels.

The tufa on the uppermost bench as observed in certain localities is a very irregular cellular mass, deposited as a coating below and extending up to the most distinct old shore line. Above this there is a well-marked wave-cut bench terminating against a cliff formed by wave plucking of the jointed volcanic rock. The tufa coating is spread over the angular talus blocks, which lie distributed in a broad band below the old beach. Many of these blocks are perched in insecure positions, except that they are in part held in place by the



tufa coating acting as a cement. The attitude and character of these deposits suggest the comparative recency of their distribution and the deposition of the tufa, subsequent disintegration and erosion having affected the deposits but little.

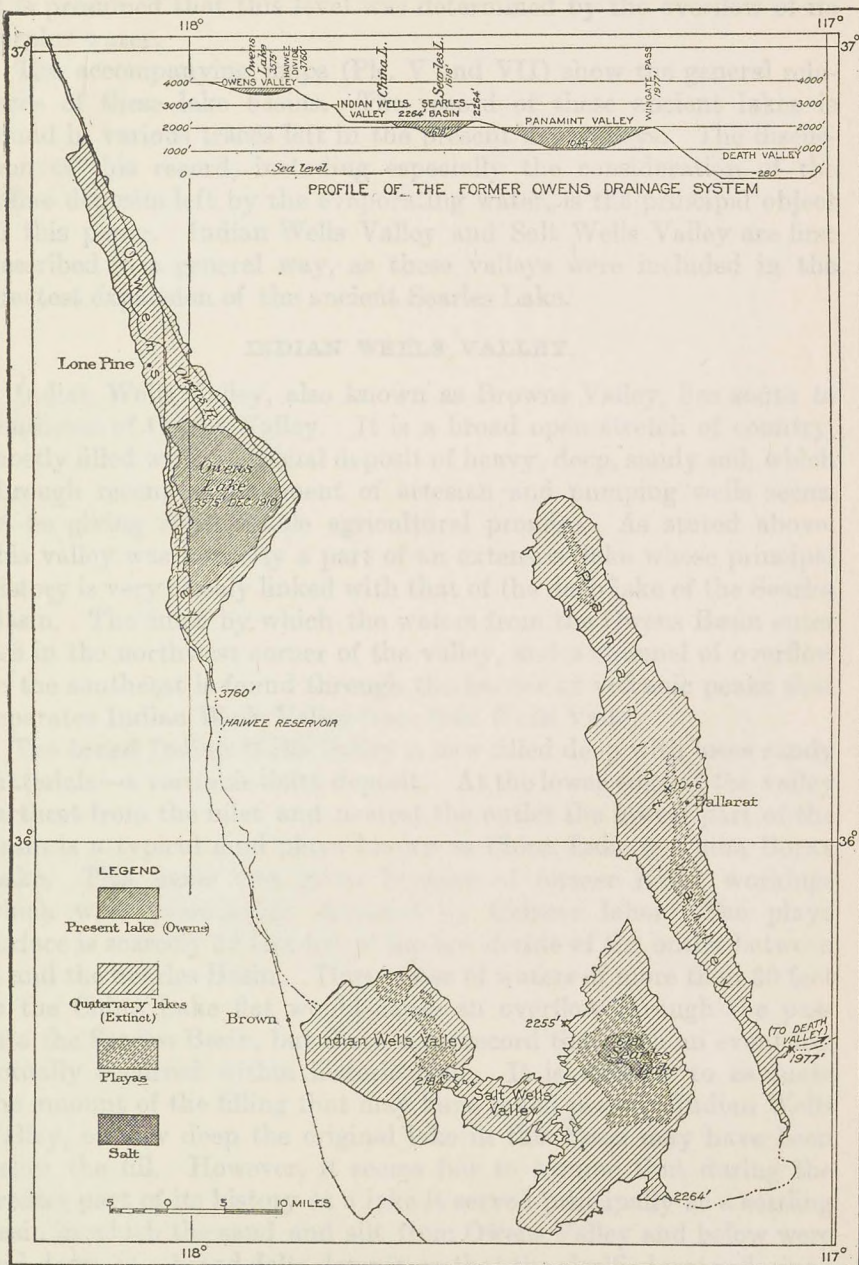
The lower tufas are quite distinct in character from the upper, wherever they have been observed. In the gulch northwest of the soda works the lower tufas stand in pinnacles of tubular structure, like inverted stalactites, having a hollow or open, porous, stemlike form, or in forms not unlike the stems of a bluntly branching tree. It is assumed that these deposits correspond to the dendritic variety of tufa described by Russell as characteristic of the lower levels in the Lahontan Basin, occurring from the bottom up to an elevation 320 feet above the level of Pyramid Lake in 1882.<sup>1</sup> In the Searles Basin the tufa was in part apparently formed by rising solutions which followed fairly distinct channels and which deposited their lime below the then existing lake water level, perhaps most abundantly close to or below one of the more permanent water levels. Some of these inverted stalactites seem to have grown up within the sandy beach or delta deposits, as it is clear that they have since been uncovered by erosion. Their forms suggest that they are the deposits of seepage waters which presumably drained into the lake as its level lowered. Possibly the readjustment of the ground-water table to meet the lowering lake surface had something to do with a temporary excess of such seepage waters along the lake shores.

#### RELATIONS TO THE OWENS RIVER SYSTEM.

It has been explained that Owens Lake during a period of former greater water supply overflowed the divide at the south end of its basin and its surplus waters flooded in turn a succession of lower basins, of which the Searles Basin was one of the largest. The Owens waters after passing the Haiwee divide dropped some 1,500 feet in about 30 miles to Indian Wells Valley and there spread out in a broad and relatively shallow sheet of water. This in turn also overflowed, its water passing by way of Salt Wells Valley and a rock-cut gorge at the lower end of that valley into the Searles Basin. Eventually the waters rose in the Searles Basin to such a height that all three of these valleys were submerged in one continuous body of water. The maximum water level in this basin was clearly determined by the elevation of an outlet pass on the south side of the basin, whence its surplus waters flowed into the extreme south end of Panamint Valley. In the Panamint Basin a history similar in some respects to that of the Searles Basin was repeated. The waters rose until the

<sup>1</sup> Recent studies by J. C. Jones have led him to the conclusion, as yet unpublished, that the dendritic and lithoid tufas of the Lahontan Basin were deposited through the agency of algæ and perhaps associated bacteria. It is possible that further study in the Searles Basin would disclose a similar origin for a part of the tufa there.



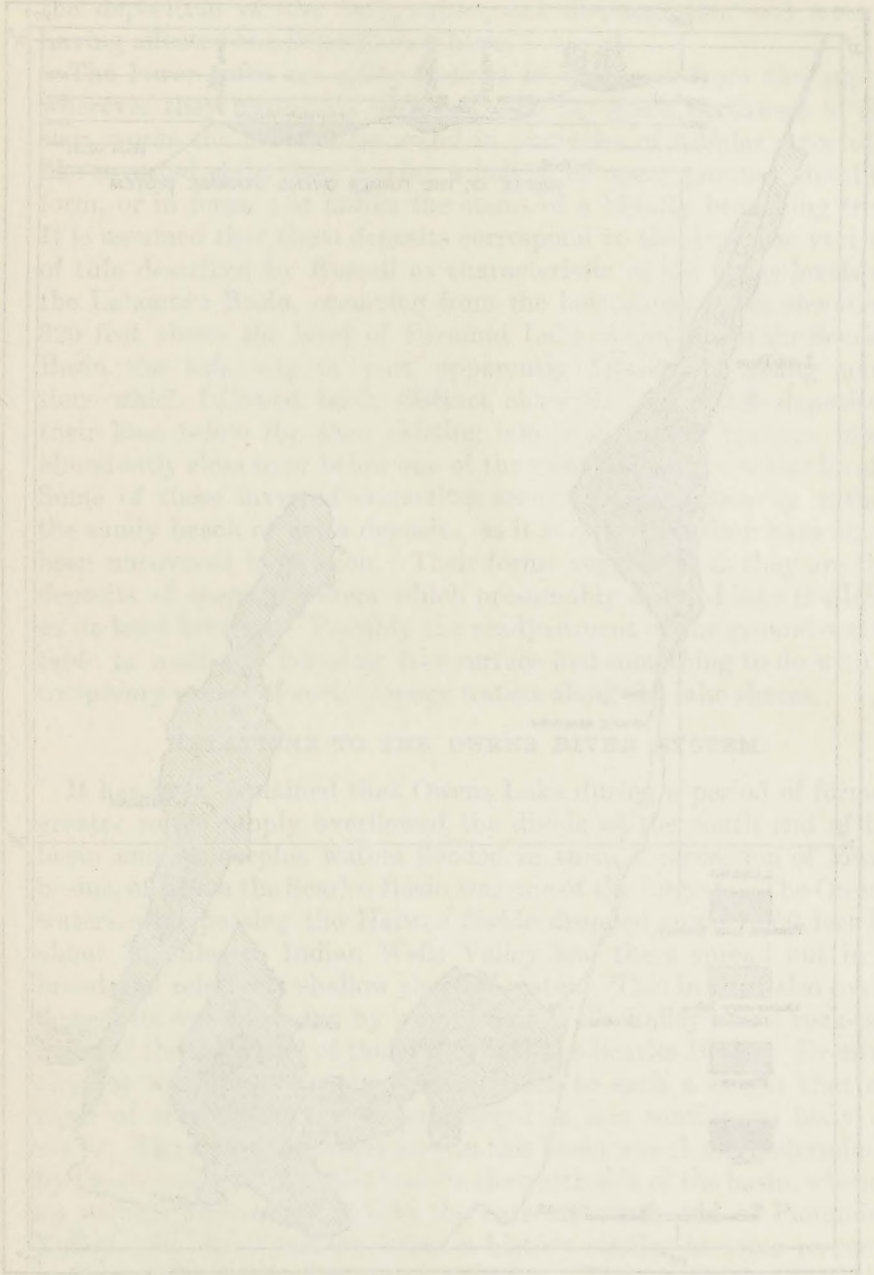


MAP OF THE FORMER OWENS, SEARLES, AND PANAMINT LAKES, CAL.



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The following table shows the number of persons who have been admitted to the State of Texas since the year 1845, and the number of persons who have been expelled from the State since the year 1845.



THE TEXAS STATE CAPITOL BUILDING. The Texas State Capitol building is located in Austin, Texas. It is a large, white, classical-style building with a central dome. The building was completed in 1888 and is one of the most important landmarks in Austin. It houses the Texas State Legislature and the offices of the Governor of Texas.



height of the lowest outlet was reached, and as they evidently remained stationary at about that level for a relatively long period, it is presumed that this level was determined by the overflow of its surplus water.

The accompanying maps (Pls. V and VII) show the general relations of these lake basins. The record of these ancient lakes is found in various traces left in the present dry valleys. The discussion of this record, including especially the consideration of the saline deposits left by the evaporating water, is the principal object of this paper. Indian Wells Valley and Salt Wells Valley are first described in a general way, as these valleys were included in the greatest expansion of the ancient Searles Lake.

#### INDIAN WELLS VALLEY.

Indian Wells Valley, also known as Browns Valley, lies south to southeast of Owens Valley. It is a broad open stretch of country, mostly filled with a surficial deposit of heavy, deep, sandy soil, which through recent development of artesian and pumping wells seems to be giving considerable agricultural promise. As stated above, this valley was formerly a part of an extensive lake whose principal history is very closely linked with that of the deep lake of the Searles Basin. The inlet by which the waters from the Owens Basin enter lies in the northwest corner of the valley, and a channel of overflow to the southeast is found through the barrier of volcanic peaks that separates Indian Wells Valley from Salt Wells Valley.

The broad Indian Wells Valley is now filled deep with loose sandy materials—a veritable delta deposit. At the lower edge of the valley farthest from the inlet and nearest the outlet the lowest part of the basin is a typical mud playa known as China Lake or China Borax Lake. This name was given because of former borax workings which were presumably operated by Chinese labor. The playa surface is scarcely 30 feet below the low divide of the outlet between it and the Searles Basin. Thus, a rise of waters of more than 30 feet in the China Lake flat would cause an overflow through the pass into the Searles Basin, but there is no record that such an event has actually occurred within historic time. It is difficult to estimate the amount of the filling that may have taken place in Indian Wells Valley, or how deep the original lake in this basin may have been below the fill. However, it seems fair to assume that during the greater part of its history as a lake it served principally as a settling basin in which the sand and silt from Owens Valley and below were laid down as a broad delta deposit, so that the clarified water drained onward through the outlet on the opposite side. That the valley was thus filled nearly to its present level with sediments while the waters continued to overflow seems more likely than that this basin



ever served as a concentrating reservoir. Certainly the configuration of the basin at the last of the lake periods, when it finally separated from the waters in Searles Lake, was practically what it is to-day, as is shown by the water lines still preserved in the sandy and alluvial slopes about its margin. Therefore the final lake in this basin probably was not much over 100 feet deep, although it was of broad expanse. The principal significance of the lake in Indian Wells Valley as a part of the system seems therefore to have been that here the bulk of suspended sand and silt was settled and only the clarified waters flowed on to the lower lakes. Possibly to this feature chiefly is due the freedom of the Searles Lake deposits from the admixture with muds that is characteristic of most desert salt deposits.

#### SALT WELLS VALLEY.

A smaller basin, known as Salt Wells Valley, constituted an arm in the ancient Searles Lake and in lower water stages formed the channel by which the Indian Wells Valley overflowed into the Searles Basin. It contains a small mud playa, but is in effect a part of the drainage area tributary to the present Searles Basin. Salt Wells Canyon, entering the main Searles Basin, is a gorge cut in granite and basalt. The channel was clearly graded to a steeper slope than that of the present stream channel. The rock-cut gorge is filled by sediments at its lower end, indicating that at some period its grade was directed to a lower level than the present surface of the deposits in the Searles Basin. This channel broadens as it approaches the Searles Lake playa, and the former gorge is filled with the pale-greenish, gently dipping or horizontally bedded lake-deposited clays or with sand and alluvial wash. This indicates that the former Searles Basin must have been far deeper than the present basin, a conclusion which is also borne out by the record of the deeper borings put down in the basin itself.

#### AREA AND VOLUME OF THE ANCIENT LAKE.

The area of the former Searles Lake at its greatest expansion, as indicated on the map (Pl. VII), was about 385 square miles. This includes both that portion which occupied the Searles basin and its extension into Salt Wells and Indian Wells valleys. At this time the level of the waters was evidently determined by the height of the outlet pass on the south side of the Searles Basin, by which the surplus waters found their way into the lower Panamint Valley.

The area and volume of the basin of this former lake have been computed from planimeter readings taken from the Geological Survey contour maps, and are tabulated herewith, the detailed figures being given also for their possible later use in other computations.



*Area calculated for lakes at various elevations in the Searles Lake basin.*

	Square miles.
2,255-foot contour (maximum water line).....	384.40
2,200-foot contour.....	275.56
2,100-foot contour.....	197.51
2,000-foot contour.....	165.74
1,900-foot contour.....	130.02
1,800-foot contour.....	110.06
1,700-foot contour.....	85.48
1,618-foot contour (elevation of salt flat).....	11.28

The volume calculations are made by assuming the whole basin to be divided into layers at the levels of the selected contours, the volume of each layer being computed from a modification of the prismoidal formula in the form  $\text{volume} = 213\frac{1}{3}l(a+b+\sqrt{ab})$ . The factor  $213\frac{1}{3}$  is introduced to give the result in acre-feet;  $l$  is the vertical interval represented by the layer concerned recorded in feet,  $a$  the area of the top level in square miles, and  $b$  the area of the basal level in square miles. The results of these computations are in round numbers as follows:

*Volume of separate layers in ancient Searles Lake.*

Including contours.	Interval.	Volume.
	<i>Feet.</i>	<i>Acre-feet.</i>
2,255-2,200 foot.....	55	11,562,000
2,200-2,100 foot.....	100	15,069,000
2,100-2,000 foot.....	100	11,609,000
2,000-1,900 foot.....	100	9,441,000
1,900-1,800 foot.....	100	7,674,000
1,800-1,700 foot.....	100	6,241,000
1,700-1,618 foot.....	82	2,727,000
		64,323,000

This total is equivalent to more than 200 times the total annual discharge of Owens River into Owens Lake at the present time or 60 times the volume of Owens Lake but is not as great as the total volume computed for Panamint Lake at its highest recorded elevation.

#### THE SALINE DEPOSITS.

The most distinctive feature of this desert basin is the immense sheet of solid white salts that lies exposed in its bottom. It is to this salt deposit that the name Searles Lake (Searles Dry Lake) has generally been applied. So far as known at present the deposit is unique in this country in the variety of its saline minerals. The immense salt fields in Death Valley are less well known and doubtless contain a larger quantity of sodium chloride and possibly other minerals, but so far as known at present they seem to be of the ordinary playa type, and so of a somewhat different class from the Searles Lake deposits.



As in other desert basins the valley deposits in the Searles Basin may be distinguished as occupying several more or less distinct areas or zones. These are:

(a) The central area of firm crusted salt, constituting what is described hereafter as the main salt deposit. This is variously estimated at 11 to 12 square miles in area.

(b) The playa zone, including the central salt area and a broad surrounding margin of salt-incrusted mud and sand, bare of vegetation, composed of salts and mixed alluvial material washed in toward the center of the basin from the surrounding valley slopes. The area of the playa zone is roughly about 60 square miles.

(c) The alluvial slopes surrounding the playa zone, composed of detrital material washed from the surrounding mountains and spread out in broad, low, flat alluvial fans, the surfaces generally covered with scattered brush. The materials of which the alluvial slopes are composed are coarser nearer their source at the mountain front and grade off in fineness toward the center of the basin until they merge with the soils in the bare playa zone.

(d) The bare rocky slopes of the bordering mountain ranges, which lie beyond and above the alluvial fans and the steeper rock-talus slopes.

The area of salt crust in the Searles Basin is roughly circular as represented on the map, elongated slightly from northwest to southeast, and almost central in the basin. It is believed to be 11 or 12 square miles in extent, as determined by the private surveys and the drilling that has been done. Its surface is the lowest part of the basin and the elevation, determined by spirit leveling in connection with the preparation of the Geological Survey map, is recorded as 1,618 feet above sea level. In unusually wet seasons surface drainage from the surrounding country sometimes floods the salt surface to a depth of a few inches. Not uncommonly a thin sheet of water, flooded out upon the flat from some local storm, is swept across the surface by the force of the wind, so that perhaps nearly the whole mass of the water is moved from one side of the basin to the other. The surface salt is dissolved to a slight extent by these floods and when it again dries the salt crystallizes with a snowy whiteness that is exceedingly dazzling in the bright sun. Dust storms, which are common to this desert region, scatter more or less dirt over the salt crust and a certain amount of such material is thus almost constantly being mixed with the salt.

The surface of the main or central salt deposit is a firm crust of salt crystals, mostly cubic halite, so hard and compact that it will support the weight of a wagon and team or even the heavy drill rig. The surface shows a tendency to crack along irregular lines, so



that it is divided into cakes or blocks. Flooding and resolution tend to level inequalities that arise and the cakes and fractures are not so pronounced a feature here as they are on some salt surfaces of similar type elsewhere.

The outline of this central solid salt area is probably not as definite as is indicated by the representation of it on the map, but it is given as interpreted from the borings that were first put down in testing these deposits. The depth of the salt is shown by the drillings to be fairly uniform and it is reported to range from about 60 feet to more than 100 feet, but probably averaging 70 to 75 feet in the main part of the deposit. In the central zone the proportion of mud layers found with the salt is comparatively small, so that the mass is in effect a solid body of salts. At and beyond the margin mud is found not only at the surface but intermingled with the salt deposits in depth, so that a sharp delimitation of the main salt deposit would probably be difficult. It is known, however, that the thick mass of solid salts is much more extensive than is indicated by the surface outline of the central salt area, and that a very considerable thickness of crystalline salts underlies a large area which is represented on the surface by playa mud and salt. Just how far this main salt body extends can of course be shown only by drilling.

The more solid part of the main deposit consists essentially of crystalline salts, in which more or less distinction by layers, from the bottom up, may be recognized, undoubtedly indicating the order of deposition in which the mass was originally laid down. This is a subject which will receive more extended consideration after the chemical data concerning the deposits have been reviewed. One of the wells drilled through the salt crust September 20, 1913, was carefully sampled, under the writer's direction, by W. B. Hicks, of the Geological Survey, and the samples are now on file awaiting mineralogic and chemical examination. All these samples consist mainly of crystalline salts more or less completely drained of the brine in which they were naturally immersed. A rough description of this record is as follows:

*Samples from well 86, Searles Lake, Cal.*

[Drilled September 20, 1913.]

No. of sample.	Character.	Depth.
		<i>Feet.</i>
1	Slightly muddy crystalline salts in coarse granular form, drained of the brine, apparently in large part halite in cubic crystals and broken fragments.	0-5
1a	Duplicate bottle sample containing selected halite crystals, showing development of octahedral forms. Crystals 1 inch or less.	
2	Clear to slightly greenish crystals drained of the mother-liquor brine, mainly showing distinct crystal forms of halite, both cube and octahedral. Coarser grained than No. 1, size of pea to $\frac{1}{2}$ inch or more in diameter.	5-10
2a	Duplicate bottle sample containing large, irregularly fractured or cleaved pieces of a clear-white saline, probably halite.	
3	Slushy sample consisting of salt crystals of distinct halite form $\frac{1}{2}$ inch or less in size in finer granular mass of smaller crystals colored by a small admixture of dull greenish mud.	10-15



*Samples from well 86, Searles Lake, Cal.—Continued.*

No. of sample.	Character.	Depth.
		<i>Fect.</i>
4	Similar in appearance to sample 3.	15-20
4a	Duplicate bottle sample containing selected white to transparent crystal fragments from same zone.	
5	A mass of wet salt crystals, slightly mashed and colored by greenish mud, mostly showing some crystal outline, size of grains of wheat to size of corn.	20-25
6	Similar to sample 5 but contains double-ended hanksite crystals with other salts.	25-30
6a	Similar to sample 6, but hanksite less abundant. Some large dark distinct crystals, undetermined.	30-32
7	Salt or saline crystals much bedaubed with dark-greenish to gray wet mud.	32-35
8	Salt grains, crystals (halite forms), and a wet mass of finer saline material, somewhat crushed and mixed with mud.	35-40
9	Clear, transparent salt grains, wheat size in general, including both coarser and finer material and some distinct hanksite crystals.	40-45
10	Salt in coarse and fine granular and cubic crystal forms, with distinct hanksite crystals, all somewhat discolored by mud.	45-50
11	Wet salts, granular and in coarser fragments, halite and possibly also other soda (?) minerals, clean from mud and drained of brine.	50-55
12	Same as sample 11.	55-60
13	White slushy mass of salts (as if coarsely ground up), containing some larger snowy-white and a few large, very dark crystals (?).	60-65
14	Same as sample 13, including a few dark crystals.	65-70
15	Mostly opaque white mass of salts drained of brine, not mixed or discolored with mud; suggests soda carbonate, trona (?), with few granular fragments and crystals like halite, perhaps halite from upper part of well. This is reported to be the bottom of the salt deposit.	70-75

NOTE.—These samples are perhaps not entirely representative of the strata at the recorded depths, as the drilling was done by means of churning with a tubular bucket, which had a flap valve and cutting shoe at the lower end, and casing was driven intermittently, so that there was more or less opportunity for sloughing of walls above into newly drilled salts below and thus of mixing the materials. However, the samples were very carefully taken and undoubtedly represent in the main and as well as could ordinarily be obtained the composition and variation of the deposit for the different intervals recorded. Unfortunately the pressure of other work in the chemical laboratory has prevented the detailed study of these samples, which will, however, undoubtedly be undertaken in due time.

The salt deposit is in effect a consolidated mass crystallized from an evaporating mother-liquor brine, in which the salts are still immersed, so that it represents a product of desiccating solutions of which the desiccation has not yet been carried to the final stages. Further evaporation of the residual liquor is checked below the reflecting white surface of the salt, and the influx of ground waters and the minor amount of surface waters from the slopes about the basin maintains the balance with evaporation. As a consequence the ground water or heavy saturated brine within the salt mass normally stands at or within a few inches of the actual salt surface. Within the salt mass below the surface the crystalline structure seems to be of such an open cellular or porous nature that the free movement of the ground liquors is not impeded to any considerable degree.

In connection with prospective utilization of the brine by pumping from this deposit attempts have been made to estimate the proportion of brine to solid crystal salts in the mass. The original estimate made in the Government announcement concerning the deposit placed the figure for the brine at 25 per cent by volume of the whole mass. More recent investigation seems to indicate that this figure was much too low. The data on which the later estimates are based are not yet available for quotation, but the interpretation given to them seems to be trustworthy.



The accompanying map (fig. 59) shows the location of the earlier holes that were drilled in the deposit, these being the basis for the outline given for the main salt deposit on the other maps. Many more wells, to the number of at least 200, have lately been sunk through the salt as far as the underlying mud, and these should give

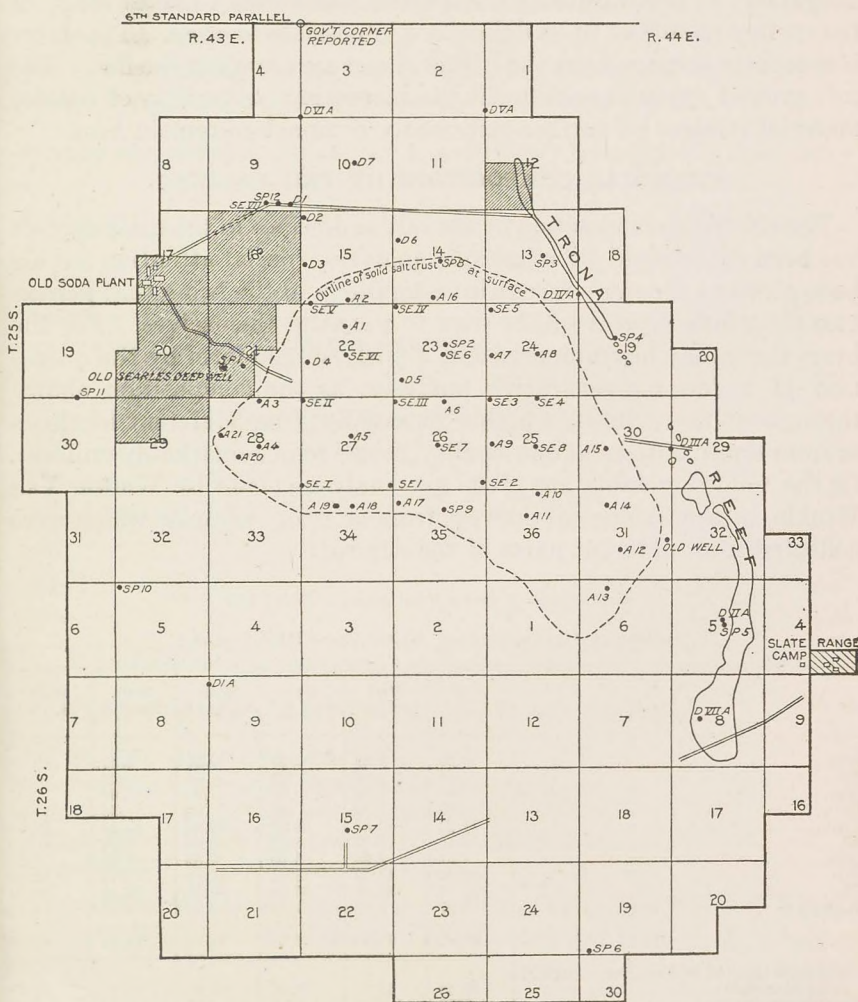


FIGURE 59.—Map of the salt deposit, Searles Lake, Cal., showing the "trona reef" and wells drilled prior to February, 1912. Based on a theoretical projection of the land survey net tied to a supposed Government corner on the north side. (Data derived from private surveys.)

a much more complete record of the extent and character of the deposit.

The soft mud zone surrounding the main salt deposit contains a very large amount of saline material which doubtless also includes much crystalline salt. Its surface, when dry, is crusted with white



salt and is not readily distinguishable from the more solid mass of the central salt area, but the proportion of mud mixed with the salts is very evidently greater toward the outer margins of the deposit. The marginal salt and mud zone rises slightly, in general only a few feet, above the level of the central part of the basin, and its surface is more irregular. It is saturated with a dense brine which makes much of the surface so soft as to be difficult or impossible to cross. The water is evidently seepage from the higher slopes surrounding the flat. The soft ground extends back until the increasing proportion of coarser material renders its surface sufficiently compact to remain firm.

#### CHEMICAL COMPOSITION OF THE SALINES.

The chemical composition of the salt and brines in the main deposit has been determined by numerous analyses, special attention having been given in the more recent investigations to the brine that permeates the whole deposit rather than to the salts themselves. For the brine these may be summarized in a fairly simple form by the quotation of a few representative analyses, as the composition shown throughout the deposit, whether in samples from different localities or from top to bottom at one locality, seems to be remarkably uniform. In the following table are given six analyses made by Walton Van Winkle, of the Geological Survey, from as many samples which were collected from different parts of the deposit:

*Composition of brine from Searles Lake, Cal.*

[Percentage of ignited residue. Walton Van Winkle, analyst.]

	Well "A 21."	Well "SP 9."	Well "SE 8."	Well "A 14?"	Well "SE 7."	Well "SE IV."
SiO <sub>2</sub> .....	0.05	0.03	0.00	0.00	0.00	0.03
As.....	.06	.06	.05	.06	.06	.08
Mg.....	.00	.00	.00	.00	.00	.00
Ca.....	.00	.00	.00	.00	.00	.00
Na.....	33.37	32.57	33.16	33.92	33.23	32.90
K.....	6.53	7.27	5.98	5.54	6.29	5.69
CO <sub>3</sub> .....	7.37	7.95	6.65	6.89	6.85	6.94
SO <sub>4</sub> .....	12.00	12.49	13.41	11.89	13.79	13.00
Cl.....	35.97	35.53	36.50	37.13	36.40	36.79
B <sub>4</sub> O <sub>7</sub> .....	3.07	1.58	1.77	2.03	2.08	4.14
	98.42	97.48	97.52	97.46	98.70	99.57
Total salts (ignited residue, percentage of original sample).....	33.48	33.94	33.30	32.96	33.21	32.88
Specific gravity.....	1.3002	1.3045	1.2969	1.2935	1.2959	1.2932

The location of all these wells is shown on the small map of the salt deposit (fig. 59, p. 275).

Each sample was collected by lowering a stoppered and weighted bottle to a depth of 35 to 40 feet in the brine and then, by means of a separate cord provided for the purpose, jerking out the stopper and allowing the bottle to fill.



The original brine contains a variable percentage of bicarbonate, which is converted to the carbonate form in the anhydrous residue and is so expressed.

Another analysis, made by W. H. Ross in the laboratory of the Bureau of Soils, Department of Agriculture, is probably the most complete statement on record as regards the composition of this brine. It represents the natural solution pumped from well "SE 7." It is given below, and for comparison is added the average of the six analyses already quoted, which corresponds very closely to it.

*Chemical composition of salts dissolved in mother-liquor brine of Searles Lake, Cal.*

	Average of six (Van Winkle).	Ross.
Total anhydrous salts (ignited residue).....	33.30	<i>a</i> 32.85
Specific gravity of brine.....	1.2974	.....
Composition of salts (as per cent of anhydrous residue):		
Na.....	33.19	33.57
K.....	6.22	6.06
Li.....	.....	.01
Mg.....	.00	Trace.
Al <sub>2</sub> O <sub>3</sub> .....	.....	.012
Fe <sub>2</sub> O <sub>3</sub> .....	.....	.003
SiO <sub>2</sub> .....	.02	.023
Cl.....	36.39	37.02
Br.....	.....	.094
I.....	.....	.004
SO <sub>4</sub> .....	12.76	12.96
CO <sub>3</sub> .....	7.11	6.70
PO <sub>4</sub> .....	.....	.30
As <sub>2</sub> O <sub>3</sub> .....	.06	.083
B <sub>4</sub> O <sub>7</sub> .....	2.45	3.00
	98.20	99.839

*a* Approximate, the specific gravity of this sample not having been determined.

The following notes are added to Mr. Ross's analysis:

Rb, Ba, NH<sub>4</sub>, NO<sub>3</sub>, Ca, Mn, Cu, none.

Loss on ignition, 0.69 per cent water and organic matter.

Sodium carbonate, 3.04 per cent in original solution.

Sodium bicarbonate, 0.75 per cent in original solution.

Potassium, 2.17 per cent in original solution.

The average analysis has been recalculated to the form of hypothetical anhydrous salts which might be derived from such a brine, as follows:

*Hypothetical average composition of anhydrous residue of brine from Searles Lake.*

Sodium chloride (NaCl).....	51.61
Sodium sulphate (Na <sub>2</sub> SO <sub>4</sub> ).....	19.22
Sodium carbonate (Na <sub>2</sub> CO <sub>3</sub> ).....	12.79
Sodium baborate (Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ).....	3.23
Potassium chloride (KCl).....	12.07
Sodium arsenate (Na <sub>3</sub> AsO <sub>4</sub> ).....	.17
	99.09



The composition of the salts has been given by private analyses, made during the testing of the deposit for soda and borax, as follows:

*Analyses of samples from well "SE 8," Searles Lake, Cal.*

Depth.	Insoluble, mud, etc.	NaCl.	Na <sub>2</sub> SO <sub>4</sub> .	Na <sub>2</sub> CO <sub>3</sub> .	NaHCO <sub>3</sub> .	NaB <sub>4</sub> O <sub>7</sub> .	H <sub>2</sub> O.
<i>Feet.</i>							
0-18	0.2	79.7	7.6	3.2	0.0	Trace.	3.3
18-25	1.4	44.0	30.5	14.8	2.5	1.0	5.8
25-30	1.4	47.3	28.1	10.6	.0	2.0	10.6
30-35	3.0	42.7	17.1	19.1	5.9	2.0	10.2
35-50	1.4	43.5	22.3	9.5	2.5	5.5	15.3
50-65	Trace.	82.8	10.6	3.2	.8	Trace.	2.6
65-79	Trace.	19.0	7.3	40.3	18.5	.5	14.4

Well "SE 8" is 1 mile due east of well "SE 7," of which the complete brine analysis is given above, and both are situated near the center of the main salt deposit. (See fig. 59.)

In these analyses potash was not determined, and presumably it is expressed as soda in the various combinations given. A single analysis showing the potash content of the salts is quoted on page 311.

The accompanying diagrams (figs. 60-74) represent graphically the variations in composition of the salts at the various depth intervals throughout the deposit. These diagrams are based on analyses of samples of salts from the borings, exclusive of the mother-liquor brine. The sites of the wells are represented on the map (fig. 59). The analyses themselves are not quoted in detail, the diagrams serving better to bring out the general significance of the results. The analyses were made by private chemists.

The diagrams are arranged roughly in geographic order, those from the center of the main deposit being placed first, followed by those to the south, to the southwest, and so on, completing the circuit of the deposit by way of the north and east.

Several noteworthy features are brought out by a comparison of the well records. One of these is the relatively inconsiderable percentage of the insoluble portion (sediment) in the main salt deposit, particularly at the center. This holds true even for the western and southwestern parts, opposite the mouth of Salt Wells Canyon, which would naturally be considered as one of the most likely sources of sediment during the formation of such a deposit. It is to be noted, however, that the outline of the main deposit as here represented is somewhat concave toward the mouth of Salt Wells Canyon and that the borings do not in fact represent any part closely adjacent to that side of the basin, and the delta may in fact be developed on that side, although it did not extend into the center of the basin during the period of salt deposition.



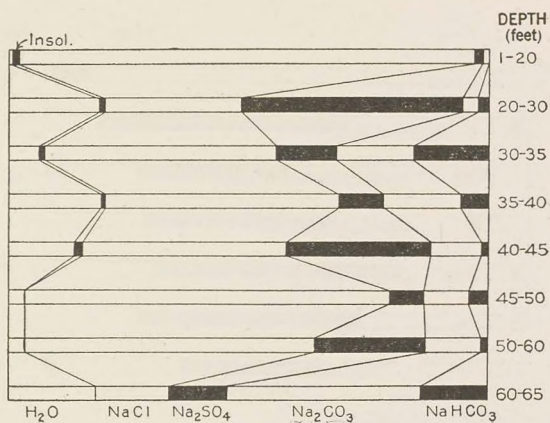


FIGURE 60.—Diagram showing variation in composition of salts at different depths in well "SE 3" (near center of main salt deposit).

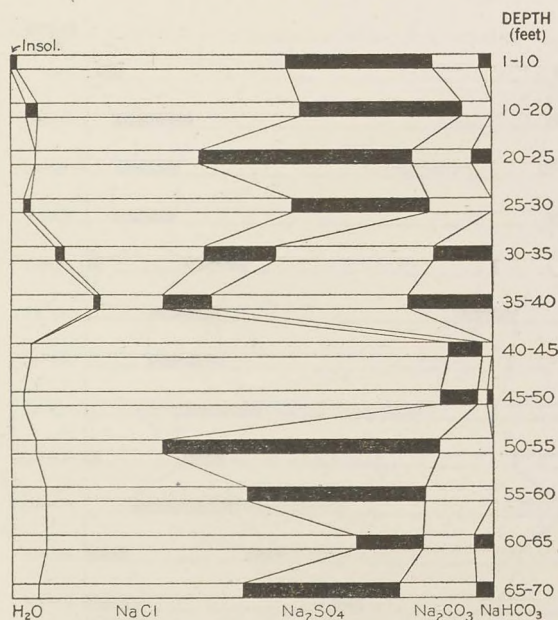


FIGURE 61.—Diagram showing variation in composition of salts at different depths in well "SE III" (near center of main salt deposit).



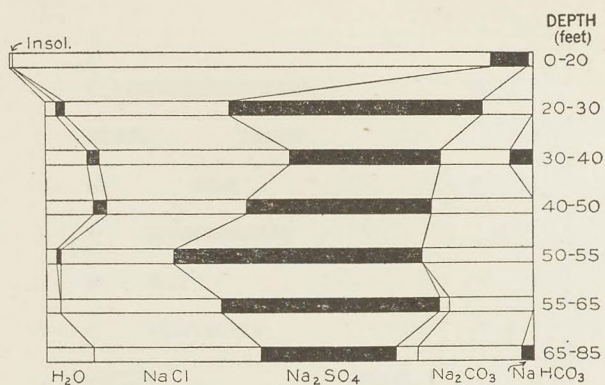


FIGURE 62.—Diagram showing variation in composition of salts at different depths in well "SE 7" (south of center of main salt deposit).

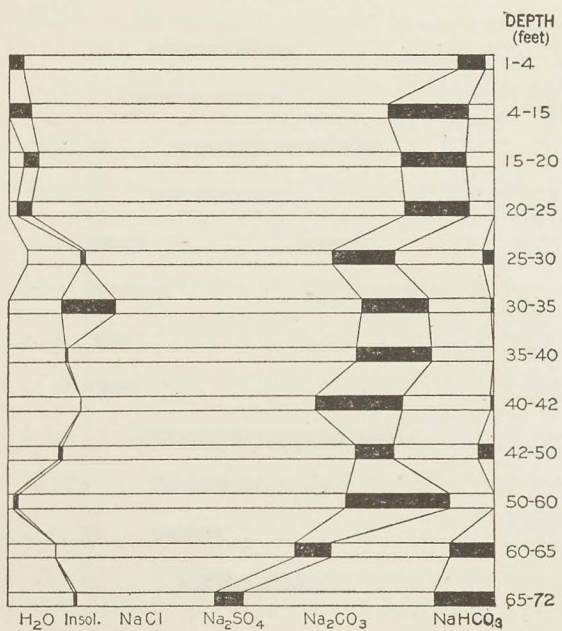


FIGURE 63.—Diagram showing variation in composition of salts at different depths in well "SE 1" (near middle of south side of main deposit).



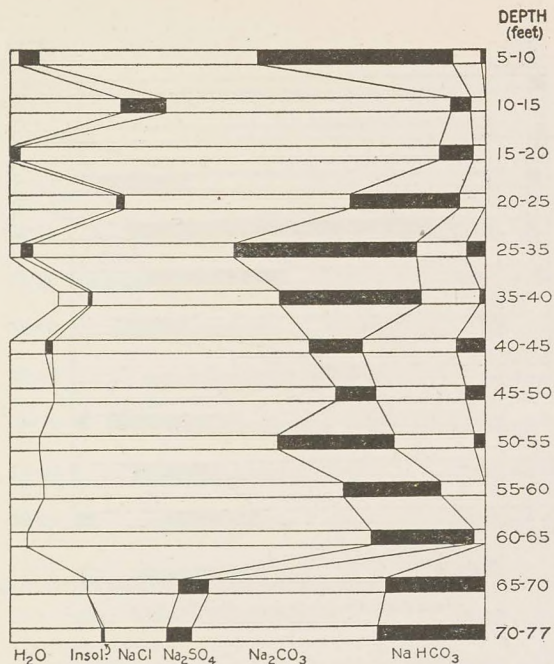


FIGURE 64.—Diagram showing variation in composition of salts at different depths in well "SE 2" (near middle of south side of main deposit).

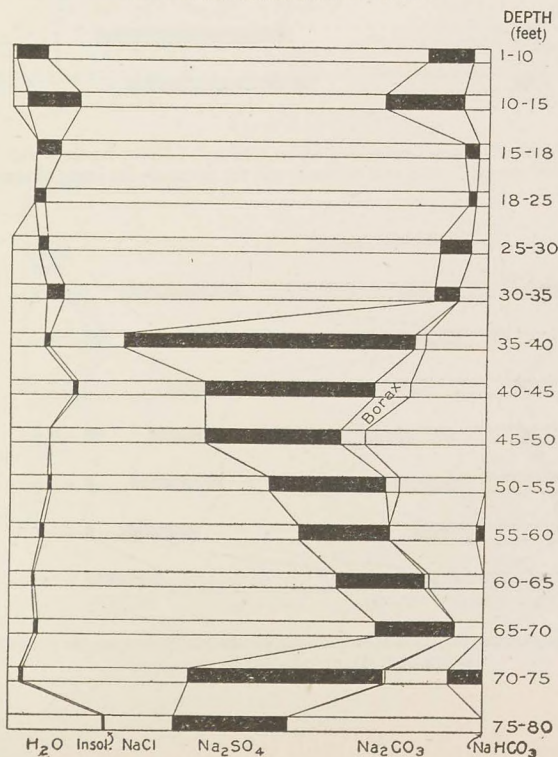


FIGURE 65.—Diagram showing variation in composition of salts at different depths in well "SE 1" (south-western part of main deposit).



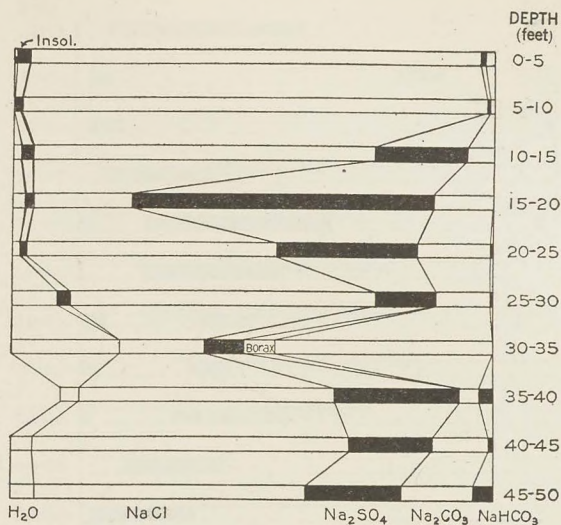


FIGURE 66.—Diagram showing variation in composition of salts at different depths in well "SE II" (western part of main deposit, close to edge).

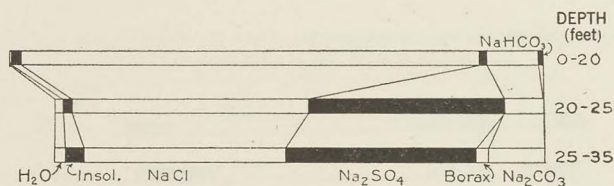


FIGURE 67.—Diagram showing variation in composition of salts at different depths in well "SE VI" (north-western part of main deposit). This well evidently did not penetrate the whole thickness of the salts.

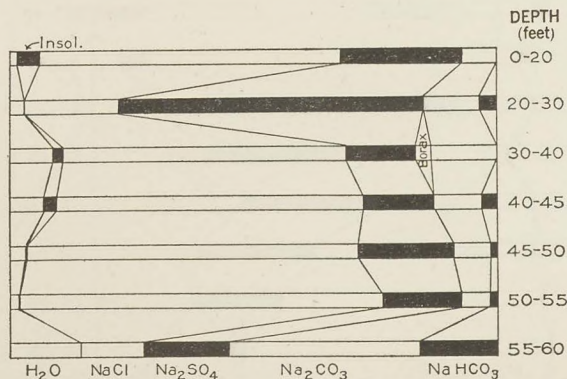


FIGURE 68.—Diagram showing variation in composition of salts at different depths in well "SE V" (north-western edge of area indicated as main deposit).



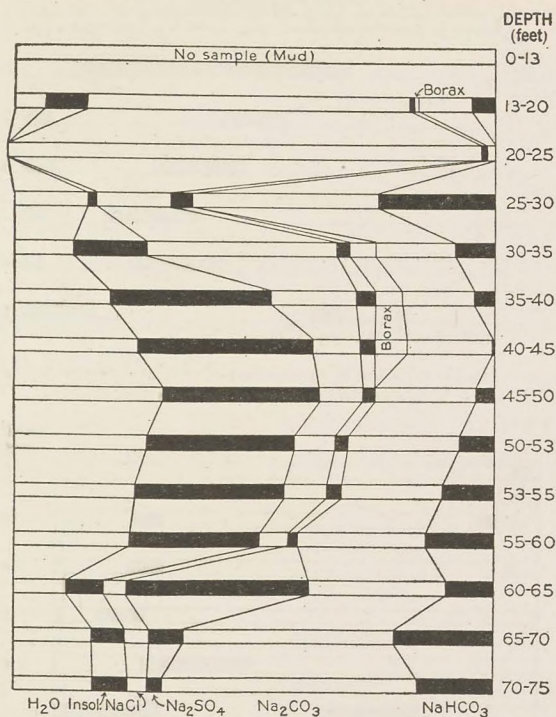


FIGURE 69.—Diagram showing variation in composition of salts at different depths in well "SE VII" (northwestern part of main deposit, outside the mapped area of the surface salt crust).

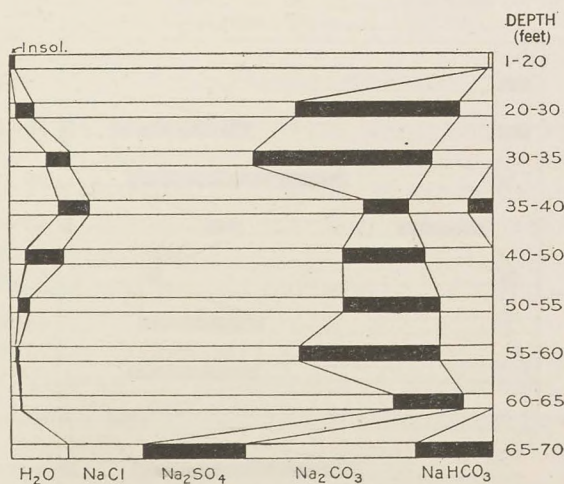


FIGURE 70.—Diagram showing variation in composition of salts at different depths in well "SE IV" (northern part of the main deposit).



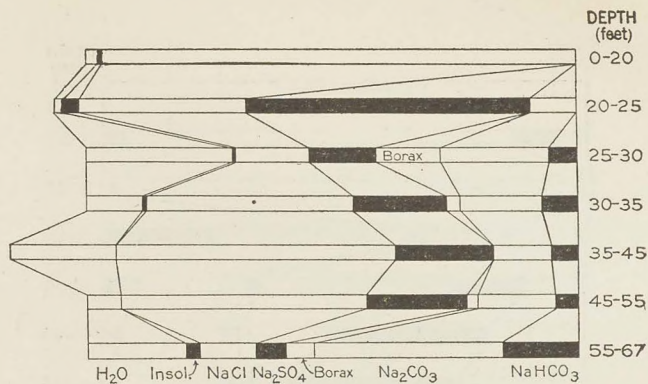


FIGURE 71.—Diagram showing variation in composition of salts at different depths in well "SE 6" (a little north of the center of the main deposit).

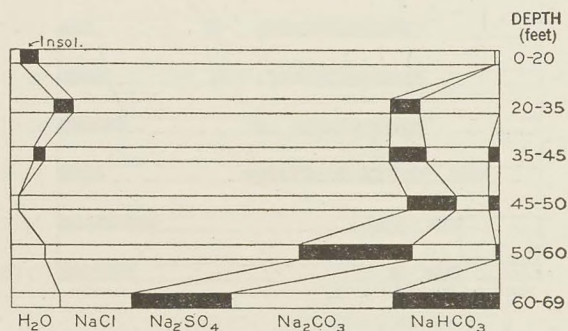


FIGURE 72.—Diagram showing variation in composition of salts at different depths in well "SE 5" (north-eastern part of the main deposit).

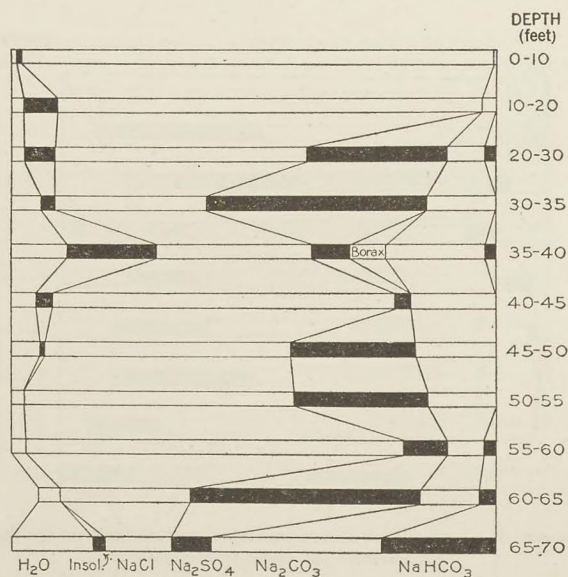


FIGURE 73.—Diagram showing variation in composition of salts at different depths in well "SE 4" (middle of east side of main deposit).



A most significant feature with reference to the chemistry of the deposits is found in the predominant deposition of sodium carbonate and bicarbonate in approximate "trona" proportions at the very bottom of the deposit. Comparison of the diagrams shows a subordinate recurrence of a similar stage at depths of 30 to 40 feet in the central part of the deposit, together with an increase in the amount of sediment (insoluble) contained and apparently a concentration of the borax at or about this general position. It is not shown by this record, but may be noted here, that the mineral hanksite and individual borax crystals, also probably sulphohalite, likewise characterize this zone. This evidence may indicate a temporary interruption of the general process of evaporation during the period while the salt deposition was going on.

The records from wells about the different parts of the margin show greater variation. There is commonly an increase in the amount of included sediment at various depths. Possibly some

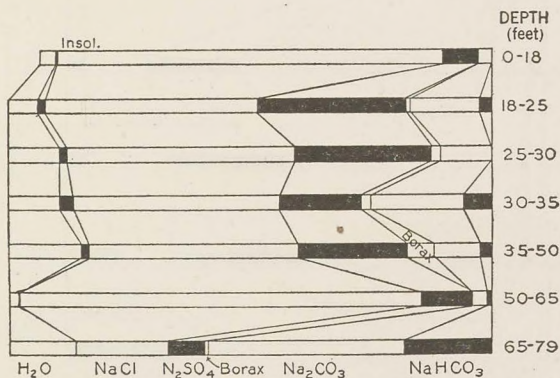


FIGURE 74.—Diagram showing variation in composition of salts at different depths in well "SE 8" (middle of eastern or southeastern part of main deposit).

parts of the deposit are richer in borax than others. The principal point that appears to be emphasized, however, is the deposition of the carbonate and bicarbonate at the base of the deposit, and the relation this bears to the evaporation experiment to be referred to presently. There is a relative increase in the sodium sulphate in the upper parts of the deposit and apparently a concentration of sodium chloride at the very top.

The experiments of Chatard<sup>1</sup> are particularly significant in considering the origin of the salt deposits at Searles Lake. They are believed to show that these deposits are the normal product of the desiccation of a body of water of the same chemical character as the Owens Lake of the present time. There can be little doubt that such waters are primarily the product of the concentration by evaporation of the natural surface drainage waters of this region.

<sup>1</sup> Chatard, T. M., Natural soda; its occurrence and utilization: U. S. Geol. Survey Bull. 60, pp. 59-67, 1890.



Chatard's experiments were conducted at Owens and Mono lakes in the summer of 1886. In these experiments measured quantities of the lake waters were set out in the open air, in receptacles, so that they might evaporate under essentially natural conditions. The volumes of the solutions were measured as they diminished, and temperature and specific gravity were determined from time to time. When deposition of the dissolved salts began, records were made, and with the development of a considerable crust or deposit the supernatant liquid was transferred to another vessel, where evaporation was again allowed to proceed. The crystalline residues were preserved for analysis. In this way the various stages of crystallization were recorded in the analyses that were obtained. In order

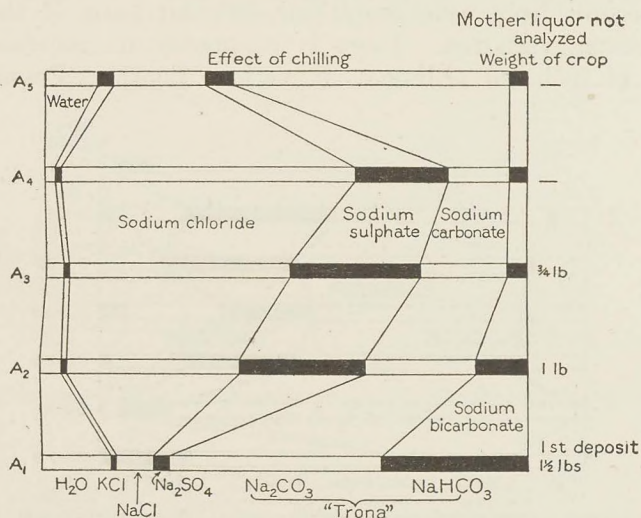


FIGURE 75.—Diagram illustrating graphically the results of Chatard's experiments with the evaporation of water from Owens Lake, Cal. A<sub>1</sub>, A<sub>2</sub>, etc., are numbers used in Chatard's tables.

to facilitate comparison the results of two sets of these determinations are plotted graphically in figures 75 and 76.

The principal features brought out by these experiments are the early deposition of the sodium bicarbonate, the almost continuous deposition of the carbonate, the lag in sulphate deposition with a tendency to concentration at an intermediate stage of the process, and the progressive increase in deposition of sodium chloride during the normal open-air evaporation of the solutions. Precipitation of the carbonate by chilling and presumably also of the sulphate at earlier stages by unusual chilling suggest variations of the order as worked out for normal conditions. In each experiment the final step was one involving an artificial condition, being the complete evaporation by artificial heat in the experiments with the Mono water and the unusual chilling of the solution in the experiments



with the Owens water. Therefore the significance of the top members of the diagram has to be read separately.

The following is a summary of Chatard's results approximately as stated by himself:

First. A deposition of calcium carbonate, beginning when the liquid has reached a specific gravity of 1.096 and attaining a maximum at 1.130-1.138.

Second or "trona stage." Incipient crystallization of the more soluble constituents, beginning when the solution has reached a concentration of 1.260, a distinct crust of salts being formed at 1.273. After a stout crust and considerable deposit of salts had formed, analysis proved it to be chiefly trona,  $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$ , as indicated in the diagrams.

Third. The formation of a product consisting in great part of sulphates and chlorides.

Fourth. The production of a mother liquor requiring an artificial heat for its further evaporation, but rich in  $\text{Na}_2\text{CO}_3$  and containing the major portion of the potash and boric acid.

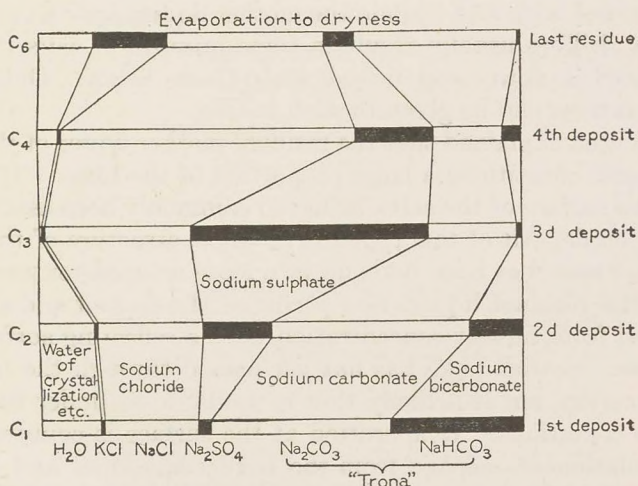


FIGURE 76.—Diagram illustrating graphically the results of Chatard's experiments with the evaporation of water from Mono Lake, Cal.  $C_1$ ,  $C_2$ , etc., are numbers used in Chatard's tables.

Unfortunately, Chatard seems to have left no record of any analysis of the final mother liquor obtained in his Owens Lake experiment, although for present considerations this is one of the most interesting of the various products, containing, as he says, the major part of the potash and boric acid salts from the original solution. A record of the final stage was obtained in the experiment with Mono Lake water.

A comparison of Chatard's experimental results with the records of composition in the Searles salt body can leave little doubt as to the manner of origin of the Searles deposit. The record of the first or calcium carbonate stage in the Searles Basin is to be reviewed presently in a description of the deposits underlying the salts. The minerals found in the Searles Basin beneath the more soluble salts are more complex than the first granular precipitate obtained by



Chatard, suggesting some mineralogic possibilities that may not have been fully appreciated in the experimental work. The lower part of the main salt deposit at Searles consists of an opaque white granular mass, more or less caked as represented in samples, having the approximate composition of trona. This is with little doubt the representative of the trona stage. Subsequent deposition in the Searles salt mass was probably influenced more or less by periodic or other changes which can not be positively determined. However, it is fair to assume that the crystallizing process has now been naturally arrested somewhere within the third or sulphate-chloride stage, with the residual mother liquor being still retained beneath the salt crust.

Analyses of salt samples obtained from borings can hardly be expected to yield entirely satisfactory results. The salts are more or less mixed with and include the mother liquor, and the methods of ordinary drilling usually result in some mixture of salts, the upper being carried down and mixed with those below. Only general interpretations can be given to such results.

It has been explained that the residual mother liquor of the Searles deposit still constitutes a large proportion of the mass. It does not lie on the surface of the salts, as has so commonly been assumed for a desiccation deposit of this type. The whole structure of the crystallizing salt mass has been built up in a loose or open-texture manner, so that the residual liquors now permeate the deposit and are largely protected from further concentration by the reflecting surface of the salt mass. Searles Lake has not yet passed through the last stages of desiccation, nor is it likely that it would do so under the present climatic conditions. Evaporation at the surface is counterbalanced by percolation or seepage from the bordering slopes and the small amount of drainage water that still finds its way in on the surface. The composition of the mother liquor may therefore have remained as at present for a long period.

#### DEPOSITS UNDERLYING THE SALT.

The nature of the deposits underlying the salt mass is known chiefly from one deep well put down on the edge of the flat southeast of the old soda works and some shallower wells that have been sunk only a short distance beneath the salt. The record of the deep well was published in part <sup>1</sup> and has been extensively quoted, as the hole has been the source of a number of entirely new saline minerals, to which further reference is made in the following pages.

It appears from this record and the more complete data now at hand that the deposits that fill this basin below the mass of solid

<sup>1</sup> De Groot, H., The Searles borax marsh, California: California State Min. Bur., Tenth Ann. Rept., p. 535, 1890.



crystallized and more soluble salts are chiefly muds, which contain, however, a very considerable amount of chemically deposited material. These deposits may therefore be presumed either to have been laid down during the earlier stages of the former very much deeper Searles water body or to represent in part playa stages of the basin preceding the final lake history. The well record indicates that such deposits extended to a depth of 625 feet or more below the present valley surface. This record is unfortunately very incomplete. The first part of it, which has been published, is given herewith, supplemented by descriptions and records lately obtained from Mr. Dennis Searles, who with his father was associated in the work of boring the well and kept the log from about the 400-foot depth to the greatest depth reached, 627 feet 10 inches. The well record is probably now as complete as it can be made. It is supplemented by analyses and descriptions of the original well samples, most of which, preserved in glass jars, were found in one of the buildings at the soda works at the time of the writer's first visit to this locality.

*Record of the Searles deep well at Searles Lake, Cal.*

Date of drilling.	Sample No. <sup>a</sup>	Strata.	Thick- ness.	Depth.
			<i>Feet.</i>	<i>Feet.</i>
1887 <sup>b</sup> .....		Salt and thenardite.....	2	2
		Clay and volcanic sand, containing a few crystals and bunches of hanksite.....	4	2-6
		Volcanic sand and black tenacious clay, with bunches of trona having black, shining luster, from inclosed mud.....	8	6-14
		Volcanic sand containing glauberite, thenardite, and a few flat hexagonal crystals of hanksite.....	8	14-22
		Solid trona, overlain by a thin layer of very hard material.....	28	22-50
		Mud, black, soft, slushy, smelling of H <sub>2</sub> S and containing layers of glauberite, soda, and hanksite; water has a density of 30° Baumé.....	20	50-70
		Clay, brown, mixed with volcanic sand and permeated with H <sub>2</sub> S. (At 300 feet "a hard streak of lime, mixed with alumina and silica; very strong test for borax").....	230	70-300
Sept. 12, 1895	1	Mud, fine, greenish (in the dry sample as preserved), filled with broken fragments of clear glassy pirssonite, which constituted the major portion of the sample saved, including also trona, some halite, and sand grains. (Sample marked 407 feet depth.) For further details see Mr. Larsen's report (p. 291)...	19	408-427
	2	Pirssonite, in broken fragments, as a fine clean glassy sand, this mineral constituting 90 per cent or more of the sample. Contains some northupite, halite, an unknown mineral called <i>a</i> , and sand grains. The northupite is in clear perfect octahedrons. Drill record says "crystal; drilling as hard as rock"...	15	427-442
	3	Pirssonite, in glassy crystalline fragments, mostly broken but some showing distinct crystal terminations, stained greenish with a small amount of mud or clay. This sample evidently represents a stratum encountered within the interval recorded. The mineral northupite is described as having been first found in clay at a depth of 450 feet in this well. E. S. Larsen reports as follows from an optical examination of this sample, "largely made up of pirssonite, and trona, <sup>c</sup> with some halite, northupite, unknown mineral <i>a</i> [see detailed microscopic report following this table], and sand grains." The northupite is in clear and perfect octahedrons.....	27	442-469

<sup>a</sup>The samples have been examined microscopically by E. S. Larsen, U. S. Geological Survey, to whom most of the mineralogic determinations should be credited.

<sup>b</sup>Commenced in 1887, according to De Groot. The well was originally bored from the surface to a depth of 400 feet, but on account of the hole going crooked it was abandoned for a time.

<sup>c</sup>Some of this material selected by Mr. Larsen was analyzed by W. B. Hicks in the Geological Survey laboratory, showing, by quantitative analysis, CO<sub>2</sub>, 24.6 per cent; HCO<sub>3</sub>, 26.4 per cent. These results calculated to trona (Na<sub>2</sub>CO<sub>3</sub>·NaHCO<sub>3</sub>·2H<sub>2</sub>O)=95.4 per cent of the whole sample. By qualitative analysis, small amounts of Cl, SO<sub>4</sub>, Mg, K, and insoluble matter present.



*Record of the Searles deep well at Searles Lake, Cal.—Continued.*

Date of drilling.	Sample No.	Strata.	Thick- ness.	Depth.
Sept. 12, 1895	4	Clay, fine, light-colored, powdery material according to dry sample, which, when examined under the microscope, proves to contain many small crystals of calcite. There is some halite, northupite, trona, mineral <i>a</i> , thenardite, and sand grains.....	<i>Feet.</i> 31	<i>Feet.</i> 469-500
Dec. 31, 1895	5	Clay, sample marked "Mud, green, with strong ammonia smell," recorded as from depth of 506 feet. The dry sample now on hand is a light-greenish clay filled with pirssonite fragments. Microscopic examination shows that the sample is about three-fourths pirssonite, with halite, northupite, thenardite, mineral <i>a</i> , claylike material, and a very few sand grains.....	15	500-515
Jan. 7, 1896	6	Clay, light brownish in dry sample now on hand, containing various insoluble mineral grains. Microscopic examination shows a few grains of pirssonite, numerous crystals of calcite embedded in halite and minutely crystalline material, probably clay, and some sand grains (like No. 10). Log notes "Borax present from surface water, not from actual crystals" At 520 feet "A hard streak 3 feet thick, test strong in borax" At 527 feet "Water from this level crystallized large cube salt in abundance when left to stand. Water also when evaporated gave very strong test in borax".....	5	515-520 520
Jan. 8, 1896	7	Clay; dry sample now on hand is light gray and contains crystals of calcite.....		527 535
	8	Shale; sample consists of several consolidated fragments, a massive aggregate composed chiefly of pirssonite, with some halite and trona, a very little sand and clay, and a few spherulites of searlesite (see specimen 9), the whole apparently representing a consolidated thin-bedded layer. Sample marked "Rimmings showing formation of parallel lines".....		540
	9	Spherulites; small rounded grains of light-gray color, containing carbonates (effervescing with acid), with some grains of quartz, feldspar, etc. Mineralogically composed of searlesite in clusters of radiating fibers with calcite embedded in it. Sample marked "Washings from mud".....		540
Jan. 13, 1896	10	Mud or clay, grayish, finely powdered in dry sample as preserved. Contains numerous crystals of calcite embedded in halite and a minutely crystalline material, probably clay, also some sand grains.....		575 580
Jan. 15, 1896	11	Clay, with a white limy appearance; light, finely powdered in dry sample as preserved; mineralogically like sample 10.....		580
	12	Clay finely pulverized; light gray in dry sample. Sample marked "Rimmings"; mineralogically like sample 10, but contains more sand grains and a few larger grains of pirssonite which might have been brought down from above.....	10	586-596
Mar. 5, 1896	13	Clay, light greenish gray; a dry powdery sample as preserved; mineralogically like sample 10.....		600
	14	Crystalline material marked "Crystal deposited by standing over night from water at 600 feet; source of water we presume 400 feet." Consists of a reddish granular and powdered crystalline aggregate colored by iron, perhaps from rusty well casing or tools, etc.....		600
	15	Crystalline material, apparently duplicate of above, marked "Crystal deposited by letting water from 600 feet stand." Is a reddish granular and pulverulent mass, about three-fourths thenardite, with considerable halite in clear grains, some grains of unknown mineral <i>a</i> , and a few grains of sand and iron rust.....		600
Mar. 9, 1896	16	Clay, in flakes of greenish color; under microscope is shown to be made up of calcite, halite, claylike material, and about 10 per cent sand grains. This sample is probably in large part detrital material. Sample marked "Soft clay underlying hard streak".....		620
	17	Mud, dried in sample as preserved, containing carbonates and grains of other minerals. Marked "Deep well, Mar. 9, 1896. Soft clay overlying at hard streak 25 feet".....		625
	18	Mud, described in well log as "fine-grained black and gray"; sample is now dry and in finely powdered state. Log records "Black and gray mud taken from deep well at 627 feet. Black turns gray on exposure." Microscopic examination gives results similar to those on sample 16.....		627
	19	Clay; sample as now on hand is fine greenish-gray pulverulent material, which under the microscope appears to be mainly clay containing calcite and halite, as in sample 16, but with a larger percentage of sand grains.....		627½

Mr. Dennis Searles states that—

In drilling the well a standard Pennsylvania rig was used. The tools were not the right kind for drilling in the lake. For instance, when the salts were hard the bit



would first pound them to a powder, then pack them. When the bit broke through the hard strata it ran wild, as the mud, which was often 4 or 5 feet in thickness between the hard strata, allowed the bit to wobble and sink as though it were in water, with the result that when it struck the hard salt strata below the drill would glance and make a crooked hole. This resulted in our having to invent tools for doing the drilling. After the tools were invented our money gave out, as all told the drilling of the well cost about \$30,000.

The mud from the lower part of the deep well was warm but not hot. My recollection on this point is very clear, as we used to "josh" and say that perhaps if we went deep enough it might get red hot. This may account for the rumors getting about that the mud was hot.

The report on the mineralogy of the samples from this well, by Esper S. Larsen, is as follows:

The material studied was powder immersed in oils of known indices of refraction and the minerals were determined by means of the petrographic microscope, supplemented by simple physical and chemical tests. The indices of refraction were measured by the immersion method, and the other optical properties were determined in the usual way. The greater part of the minerals were readily and positively determined by optical methods, but in some very fine fibrous minerals were not positively identified. No attempt was made to determine all the minerals present in small amount, as the material available was not thought to justify such exhaustive study.

*Specimen 1.*—Chiefly pirssonite with considerably less of unknown mineral *a*, trona, halite, and sand grains. Pirssonite makes up nearly all the grains which do not pass a 40-mesh sieve.

Pirssonite in clear crystals or in crystals dull from a coating of dusty minerals or from inclusions makes up the greater part of the sample, especially of the coarser part. Many of the crystals are pitted and rough, probably from corrosion. It has a vitreous luster, a conchoidal fracture, and the following optical properties:  $\beta=1.510$ ;  $\gamma-\alpha$ , very strong; optically +;  $2E = \text{about } 48^\circ$ . Dispersion  $\rho < \nu$  rather strong,  $Bx_a$  normal to tabular crystals. In part it is in good crystals of the habits figured in Dana's "System of mineralogy."

The powdery material coating the pirssonite and making up much of the fine material of the sample is greenish gray in color and is largely one mineral. Under the microscope it is seen to be an aggregate of minute fibers, some arranged in well-formed spherulites. They have a mean index of refraction of about 1.53, a birefringence of about 0.01, and negative elongation. They may be gypsum.

Trona is confined to the fine material and makes up only a small percentage of the sample. It is in rude lath-shaped or prismatic crystals with negative elongation and with *Y* emerging from the flat face. Its indices of refraction are:  $\alpha=1.41$ ;  $\beta=1.49$ ;  $\gamma=1.54$ . It is optically — and has a large axial angle. It is commonly embedded in the unknown mineral *a*.

Halite is present in the fine material cementing the other minerals. Isotropic:  $n=1.542$ . Tastes salty.

Detrital grains form only a small percentage of the material and occur only in the finer part. Chlorite, hornblende, quartz, plagioclase, orthoclase, etc., were recognized.

*Specimen 2.*—This sample is made up very largely of pirssonite with some northupite, halite, unknown mineral *a*, and sand grains.

The northupite is in clear and perfect octahedrons. It is isotropic and has an index of refraction of 1.515. The other minerals have their usual properties. The sand grains are microcline, quartz, plagioclase, chlorite, hornblende, etc.



*Specimen 3.*—Much of this material is in grains several millimeters across. The sample is made up largely of pirssonite and trona, with some halite, northupite, unknown mineral *a*, and sand grains.

The trona is in large crystal fragments which show one very perfect cleavage. In part they are clear and glassy, in part grayish and dull. They have the following optical properties:  $\alpha=1.410\pm0.005$ ;  $\beta=1.492\pm0.005$ ;  $\gamma=1.542\pm0.005$ . Optically —;  $Bx_a$  emerges normal to the cleavage.  $\rho < \nu$  rather strong.  $2V=76^\circ$ , computed from the values of  $\alpha$ ,  $\beta$ , and  $\gamma$ .

*Specimen 4.*—This sample consists chiefly of fine material, resembling that of specimen 10. The larger grains are mainly pirssonite. There is some halite, northupite, trona, unknown mineral *a*, thenardite, and sand grains of chlorite, feldspar, quartz, hornblende, etc.

*Specimen 5.*—This sample is about three-fourths pirssonite, with halite, northupite, thenardite, unknown mineral *a*, claylike material, and a very few sand grains.

*Specimen 6.*—Similar to No. 10. A few grains of pirssonite.

*Specimen 7.*—Similar to No. 10.

*Specimen 8.*—Massive fragment, mainly pirssonite, with some halite, trona, searlesite (see specimen 9), sand grains, etc. Part of this is similar to No. 10.

*Specimen 9.*—Chiefly spherulites of radiating fibers of the new mineral searlesite, with  $n=1.525$  and birefringence about 0.01,  $2V$  large, elongation +, and extinction not parallel. It has the composition  $Na_2O.B_2O_3.4SiO_2.2H_2O$ . Embedded in this are numerous crystals of calcite. There are very few sand grains.

*Specimen 10.*—Very fine grained. Numerous crystals of calcite embedded in halite and minutely crystalline material, probably clay. Some sand grains.

*Specimen 11.*—Similar to No. 10.

*Specimen 12.*—Similar to No. 10. More sand grains and a very few large grains of pirssonite (which might have been brought down from above during drilling?).

*Specimen 13.*—Similar to No. 10.

*Specimen 15.*—About three-quarters thenardite, with considerable halite in clear grains, some grains of unknown mineral *c*, and a few grains of sand and iron rust.

The thenardite has the following optical properties:  $\alpha=1.464\pm0.003$ ;  $\beta=1.474\pm0.003$ ;  $\gamma=1.485\pm0.003$ ; optically +;  $2V$  nearly  $90^\circ$ ;  $\rho > \nu$  perceptible. It is partly in large crystal grains, partly in aggregates of small grains.

The unknown mineral is in grains and aggregates of small grains. It has the following optical properties:  $\alpha=1.445$ ;  $\beta=1.482$ ;  $\gamma=1.490$ ;  $2E$  about  $46^\circ$ ;  $\rho > \nu$  moderate; optically —.

*Specimen 16.*—The sample is a very fine grained shaly material and is made up of calcite, an unknown mineral, halite, claylike material, and about 10 per cent sand grains. The calcite is in good rhombic crystals embedded in the halite clay and unknown mineral. The unknown mineral has a low birefringence and a mean index of refraction of about 1.53 and is probably optically + with a large  $2V$ . It may be gypsum or a kaolinitic mineral.

*Specimen 18.*—Similar to No. 16.

*Specimen 19.*—Similar to No. 16, with more sand grains.

The iron rust noted in the well record is doubtless derived from the casing or some tools or equipment used in the drilling. The principal feature brought out by the careful study of these samples is that they consist almost entirely of chemically deposited minerals, with a relatively minor proportion of detrital materials. While this is true of the specimens now at hand, there is some question as to whether such a generalization would hold for all the material that must have been removed by drilling. Interest in sampling naturally centered on the



more unusual products, and some of the material, such as the spherulites of searlesite of sample 9, have the appearance of having been washed or panned to free them of any inclosing mud or admixed materials.

The halite noted in several of the samples may not be an original constituent of the material, as it is very likely to have been introduced by the use of the saturated surface brines for drill waters, and this may also hold true for other soluble constituents that have been determined—for example, some of the thenardite.

Aside from the incompleteness of the log and the possible inadequacy of the samples, the entire significance of this well record is difficult to interpret. The minerals pirssonite, northupite, glauberite, gaylussite, and others, to be described more fully later, belong to a class of the less readily water-soluble salines which might have been either deposited from saturated solutions in a concentrating lake or formed as layers more or less mixed with muds under playa conditions, where they were subject to alternate shallow inundation and desiccation. They undoubtedly belong to a class of minerals which are among the first to be deposited with the concentration of the waters, representing the forms in which principally the lime and magnesia are separated from the solution. Glauberite and gaylussite have been found in Columbus Marsh, Railroad Valley, and elsewhere in Nevada, where they were probably formed in muds as playa deposits, and glauberite has been found in Death Valley, Saline Valley, and elsewhere in California under similar conditions. The distribution of nearly all the minerals as more or less well defined, completely formed crystals embedded in mud, is suggestive of the playa mode of their formation, but it must be admitted that the evidence of the exact manner of their deposition is as yet very far from conclusive.

It is a most natural assumption that the less soluble minerals which seem to characterize the deposits underlying the salt to a depth of at least 540 feet and perhaps deeper may be the first products of deposition in the original concentration of the Searles Lake waters. Reasoning from Chatard's experiments suggests that they may thus indicate that stage in which the Searles waters first reached a density of about 1.1. It is also reasonable to suppose that a certain amount of sediment, such as silt or fragmental material or dust, would be more or less constantly entering the lake and settling with the minerals as they were deposited. Such a stage had probably already been passed through in the present Owens Lake when in recent years its water reached a maximum recorded density of 1.195. For this reason pirssonite and possibly also the other rare minerals might even now be recovered by dredging the muds at the bottom of Owens Lake. Conditions are not, of course, entirely comparable within these two basins, but the analogy is interesting. At any rate, it serves to indi-



cate the rather likely possibility that the old Searles Basin, even during the later stages in the concentration of its waters, may have been considerably deeper than it is at present, and that it may have borne much the same relation to the whole drainage system that Owens Lake does to-day. If so, the desiccation of Searles Lake has been a long and possibly a frequently interrupted process.

#### THE "TRONA REEF" AND BORAX DEPOSITS.

Among the more superficial deposits of the region, one feature that deserves mention is the "trona reef." At the eastern and north-eastern margins of the main playa zone rises a rim of crusted salts a few feet above the level of the flat and just at the foot of the alluvial slope of sand and coarser wash from the mountains. The deposit is of the nature of a saline efflorescence, being composed of salts brought up with rising ground water and deposited at the surface by evaporation. The "trona reef" at Searles Lake is one of the most massive deposits of this character that has been observed, although this feature is a common one about playa deposits generally, usually showing as a marginal rim of white efflorescent salts about the outermost edge of the bare, flat mud zone.

The position of the trona reef is indicated in figure 59 (p. 275). This was one of the features that first attracted attention to the Searles Lake deposits—in fact, a single tract of 160 acres at the north end is patented land originally taken up with a view to working these salts. The remains of a large steel-frame machine for hoisting and loading the salt still stand on the ground. The deposit is reported to consist chiefly of trona ( $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$ ), and it is presumed that the material was to have been utilized directly for the production of soda ash. That the trona should have been selectively crystallized in this zone is perhaps somewhat unusual but may be accounted for by supposing it to be a product pertaining to the second or trona stage as illustrated in the experiments on evaporation of the water from Owens Lake.

The composition of the "trona reef" is expressed in the following analysis, which was made by private chemists but is believed to be representative. It is an analysis of a composite of a number of samples taken from different points on the deposit.

*Analysis of samples from "trona reef," Searles Lake, Cal.*

Insoluble in water.....	13.33
NaCl.....	19.60
$\text{Na}_2\text{SO}_4$ .....	5.05
$\text{Na}_2\text{CO}_3$ .....	27.60
$\text{NaHCO}_3$ .....	20.60
$\text{Na}_2\text{B}_4\text{O}_7$ .....	1.52
KCl.....	1.50
	<hr/>
	100.00



The composition of pure trona ( $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$ ) is:

$\text{Na}_2\text{CO}_3$ .....	46.90
$\text{NaHCO}_3$ .....	37.17
$\text{H}_2\text{O}$ .....	15.93
	<hr/> 100.00

In the anhydrous salt the proportion  $\text{Na}_2\text{CO}_3 : \text{NaHCO}_3 = 55.79 : 44.21$ . Thus the composition given for the trona reef allows for 46.6 per cent of the dehydrated trona, mixed with sodium chloride and other constituents.

Although surface drainage in this region is a relatively inconsiderable factor, the porous alluvial fill of the valleys constitutes an immense underground storage reservoir which is kept constantly filled. The outspread of material from the mountain slopes has been accomplished by the action of running surface waters. As is generally recognized, the coarser materials and the more steeply graded slopes lie next to the source of supply, and the materials grade off into finer deposits or alternating fine and coarse layers as they extend outward into the valley. A distinct and presumably steady movement of ground waters within these alluvial deposits toward the valley bottom is to be recognized in the shallow wells and the springs or marshy ground which they produce at the lower edge of the alluvial slopes. When this ground water encounters the saturated and less pervious deposits in the bottom of the basin its level rises. Where it does not actually flow out in springs, it lies so near the surface that moisture is constantly rising by capillarity. Its evaporation there produces the rim of salts so characteristic of the margins of many desert or playa deposits. The trona reef is a result of such influences.

Former borax workings about the basin were situated in the margin of the deposits in or near the zone of soft muds and rising ground waters. The mineral ulexite ("cotton ball") is said not to have been found in this deposit,<sup>1</sup> the borax having occurred in the form of natural sodium borate only. The "crude borax" at Searles Lake has been described as found on the surface of the "higher parts of the lake," presumably the slightly more elevated portions of the marginal playa mud zone, in a condition resembling burnt bone. Underlying this material, according to the description, was found a very hard, uneven deposit of different salts, which was generally not disturbed. The "crude borax" was collected to a depth varying from 2 to 8 inches.

There were at least two plants in the former borax workings, the old plant of the San Bernardino Borax Co. situated at the northwest corner of the flat, west of the soda works, and a smaller plant at the extreme north end of the flat, below the station now known as Tanks.

<sup>1</sup> De Groot, H., The Searles borax marsh, California: California State Min. Bur. Tenth Ann. Rept., p. 537, 1890.



The reference by De Groot mentioned above is a description of the equipment and operations of the San Bernardino Co. The surface crust collected from the mud about the margin of the marsh was hauled to the reducing plant, where it was stored in a stack. The stacked material was thrown into dissolving tanks filled with the boiling solution and there kept until it was completely dissolved. Free ammonia is said to have been given off during this process. The heat was supplied through steam coils in the bottom of the tanks, the pipes being pierced with small holes to let off condensed steam. The hot solution, after standing eight hours to settle, was run into long wooden tanks where it cooled and crystallized. In five to nine days crystallization was complete, the product being borax of varying degrees of purity.

#### RED COLOR IN THE SALTS AND BRINE.

The surface salt and the strong brine standing in trenches or in pools about the margin of the salt deposit is characterized by a deep-red color, which is also imparted to some of the salt crystals at the surface of the deposit. The nature of this color has been discussed by Chatard and others, but the following quotation from Lunge<sup>1</sup> is perhaps the latest statement published with reference to its appearance in these particular deposits:

The red color exhibited by many alkaline salt lakes, which is often also apparent in the salts deposited, is ascribed by Payen<sup>2</sup> to the presence of small crustaceans, *Artemia salina* Leach (*Cancer salinus* Linné), which appear in large masses when the water has attained a density of 1.16 and which are of a gray or greenish color; on further concentration to specific gravity 1.21 they die and form a red froth at the surface. \* \* \* I, for my part, must decline to accept the assumption that the red color is regularly caused by the presence of *Artemia* or other animal organisms, if it is ever due to that cause; for the samples of red water which I had myself taken from the lakes of the Wade Atrun have preserved that color during the many years I have kept those samples. It remains after frequent filtrations. The red filtrate shows nothing under the microscope; the color is at once discharged by adding nitric acid or hypochloride and hydrochloric acid and is evidently caused by organic substances present in solution. There is no iron present.

#### MINERALOGY OF THE SEARLES LAKE DEPOSITS.

##### MINERALS CONTAINED.

Of the commoner minerals characteristic of desert-basin salines generally, probably the greater number are represented in the Searles Lake deposits, except ulexite, which is reported to be absent. The minerals found are included in the following list, arranged approximately, though not exactly, in the order of abundance. The list is not assumed to be complete, as the deposit has not yet been made

<sup>1</sup> Lunge, George, Sulphuric acid and alkali, vol. 2, pt. 1, p. 58, 1909.

<sup>2</sup> Annales chim. et phys., 2d ser., vol. 65, p. 156.



the subject of a thorough mineralogic study and these minerals belong to a group which is not generally well known and whose recognition depends to a large extent on detailed chemical or optical mineralogic work. The solubility in water is indicated in the list.

Halite.....	NaCl. Very soluble.
Mirabilite.....	Na <sub>2</sub> SO <sub>4</sub> .10H <sub>2</sub> O. Very soluble.
Thenardite.....	Na <sub>2</sub> SO <sub>4</sub> . Very soluble.
Trona (urao).....	Na <sub>2</sub> CO <sub>3</sub> .NaHCO <sub>3</sub> .2H <sub>2</sub> O. Readily soluble.
Natron.....	Na <sub>2</sub> CO <sub>3</sub> .10H <sub>2</sub> O. Very soluble.
Borax.....	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> .10H <sub>2</sub> O. Very soluble.
Gypsum.....	CaSO <sub>4</sub> .2H <sub>2</sub> O. Slightly soluble.
Anhydrite.....	CaSO <sub>4</sub> . Slightly soluble.
Glauberite.....	CaSO <sub>4</sub> .Na <sub>2</sub> SO <sub>4</sub> . Slightly soluble.
Hanksite.....	9Na <sub>2</sub> SO <sub>4</sub> .2Na <sub>2</sub> CO <sub>3</sub> .KCl. Readily soluble.
Northupite.....	MgCO <sub>3</sub> .Na <sub>2</sub> CO <sub>3</sub> .NaCl. Slightly soluble.
Pirssonite.....	CaCO <sub>3</sub> .Na <sub>2</sub> CO <sub>3</sub> .2H <sub>2</sub> O. Slightly soluble.
Gaylussite.....	CaCO <sub>3</sub> .Na <sub>2</sub> CO <sub>3</sub> .5H <sub>2</sub> O. Slightly soluble.
Sulphohalite.....	2Na <sub>2</sub> SO <sub>4</sub> .NaCl.NaF. Slightly soluble.
Tychite.....	2MgCO <sub>3</sub> .2Na <sub>2</sub> CO <sub>3</sub> .Na <sub>2</sub> SO <sub>4</sub> . Almost insoluble.
Searlesite.....	Na <sub>2</sub> O.B <sub>2</sub> O <sub>3</sub> .4SiO <sub>2</sub> .2H <sub>2</sub> O. Almost insoluble.

Several other more or less common minerals, including celestite, cerargyrite, colemanite, dolomite, embolite, gold, niter, and sulphur have been said to be present in these deposits. The report covering colemanite seems to have originated in an article in the American Journal of Science, December, 1884, and is supposed to be an error or a misinterpretation, as colemanite is not known elsewhere in association with desiccation products in dry-lake basins. Niter has been reported in the clay hills at the south end of the Searles Basin, but not, so far as known, in any immediate relation to the main saline deposits. Calcite occurs in the sands of the deep well and in the tufa deposited on the old lake shores. Most of the other minerals reported, although doubtless found in the vicinity, are of doubtful significance in relation to the saline or dry-lake deposits.

The deep well at Searles Lake, which was begun in 1887 and completed in 1896 and the log of which has already been reviewed, has proved a veritable treasure house of unusual and entirely new minerals, including several that have never been found at any other place. The less soluble minerals were mostly found embedded in the muds or clay at the margin or underlying the main saline deposit. Several are characteristically found in small but distinctly formed crystals, many of which are unattached, as if they had grown within the mud. In places, however, layers of the crystalline material (as pirssonite) have become so consolidated as to present hard strata, offering considerable difficulty in drilling. Many of the specimens obtained as drill samples are fractured masses or even finely granulated material, but much perfectly preserved crystalline material has also been obtained in this way.



In the following pages is given a brief review of the more salient physical properties of these saline minerals. Acknowledgment is due to Mr. W. T. Schaller, of the United States Geological Survey, for the crystal drawings and sketches, prepared largely from material collected by the writer and also from published references.

#### HALITE (COMMON OR ROCK SALT).

Sodium chloride, or halite ( $\text{NaCl}$ ; sodium ( $\text{Na}$ ) 39.4, chlorine ( $\text{Cl}$ ) 60.6), is a colorless, transparent substance having a brilliance like glass, or, as it is commonly found in nature, white in crystalline or granular form. It occurs crystallized in distinct forms or in compact massive deposits, in places more or less colored by impurities. Its hardness is 2.5 and its specific gravity 2.1 to 2.2. It crystallizes in the

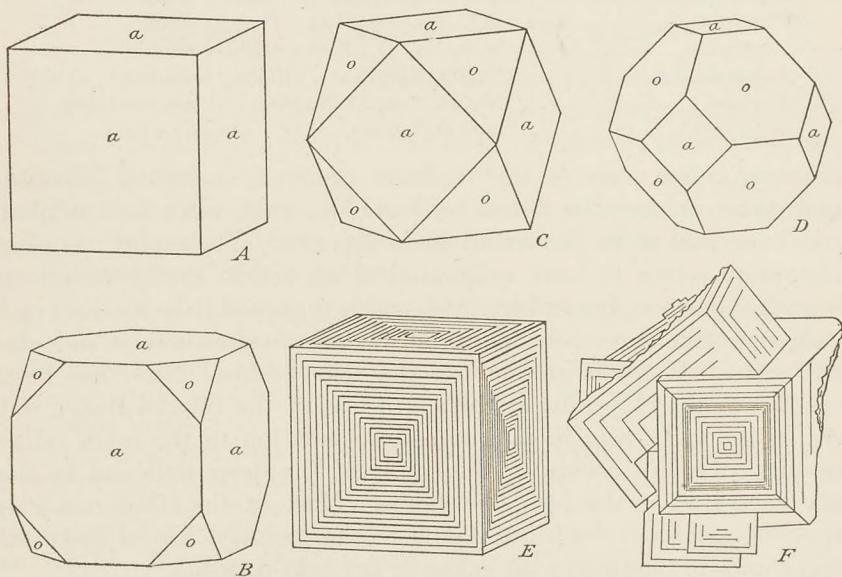


FIGURE 77.—Halite from Searles Lake, Cal., cubic (*a*) and octahedral (*o*) forms. Crystal drawings and sketches.

anhydrous form in the isometric system, usually in cubes, which commonly unite or intergrow to build up the well-known "hopper forms." In the saline deposits of the desert basin it is also frequently found in octahedral forms. It has perfect cubic cleavage and conchoidal fracture. It is very readily soluble, 100 parts of pure water at  $0^{\circ}\text{C}$ . dissolving 35.59 parts  $\text{NaCl}$ , and this solubility is but little increased by a rise in temperature, as at  $30^{\circ}\text{C}$ . only 36 parts are dissolved. Halite has a strong saline taste. (See fig. 77.)

#### MIRABILITE (GLAUBER SALT).

Decahydrated sodium sulphate, or mirabilite ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ; sulphur trioxide ( $\text{SO}_3$ ) 24.8, soda ( $\text{Na}_2\text{O}$ ) 19.3, water ( $\text{H}_2\text{O}$ ) 55.9), is a colorless, transparent crystalline salt, which separates from its solutions



by evaporation in the open air or by chilling of its saturated solutions below  $33^{\circ}\text{C}$ ., the separation being accompanied by evolution of heat. It forms in large crystals, often needle-like, with the development of many faces in a long, prismatic form. Its hardness is 1.5 to 2 and its specific gravity 1.5. It crystallizes in the monoclinic system. The crystals are readily efflorescent in dry air, losing their water and falling to a white powder. Its common occurrence in nature is therefore in standing saturated solutions or mixed in other salts. It is very soluble in water and its solubility increases markedly with a rise

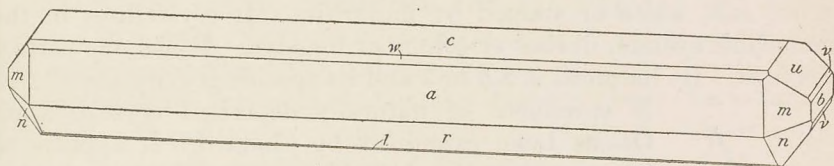


FIGURE 78.—Mirabilite.

in temperature. At  $0^{\circ}\text{C}$ . 100 parts of water dissolves 5.02 parts  $\text{Na}_2\text{SO}_4$ , while at  $33^{\circ}\text{C}$ ., the point of its greatest solubility, the same quantity of water dissolves 50 parts  $\text{Na}_2\text{SO}_4$ . Its taste is cool, then feebly saline, with a bitter aftereffect. (See fig. 78.)

#### THENARDITE.

Anhydrous sodium sulphate, or thenardite ( $\text{Na}_2\text{SO}_4$ ; soda ( $\text{Na}_2\text{O}$ ) 43.68, sulphur trioxide ( $\text{SO}_3$ ) 56.32), occurs in crystalline form or finely powdered as a result of dehydrating crystallized mirabilite.

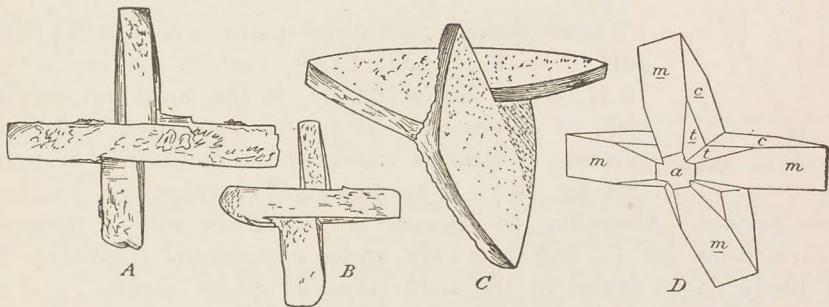


FIGURE 79.—Twinned thenardite. Crystal drawing from Dana; sketches of crystals from Searles Lake, Cal., by W. T. Schaller.

It forms clear transparent to brownish crystals, the color being due to included impurities. It crystallizes in the orthorhombic system in pointed pyramids, combined into crusts, with surface rough. The crystals are commonly twinned, as in some specimens from Searles Lake. (See fig. 79.) In the air it becomes dull by absorbing water. Its specific gravity is 2.655. It results from the evaporation of solutions above  $33^{\circ}\text{C}$ . or from strongly alkaline solutions, as by the addition of sodium carbonate, at ordinary temperatures. It is very soluble in water and has a faintly saline taste.



## TRONA (URAO).

Trona, or urao ( $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$ ; sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) 46.90, sodium bicarbonate ( $\text{NaHCO}_3$ ) 37.17, water ( $\text{H}_2\text{O}$ ) 15.93; or in the other form carbon dioxide ( $\text{CO}_2$ ) 38.9, soda ( $\text{Na}_2\text{O}$ ) 41.2, water ( $\text{H}_2\text{O}$ ) 19.9), is undoubtedly the most important of the natural soda minerals and constitutes the greater part of most natural soda deposits. It occurs as beds of white cavernous material with acicular or bladed crystals lining the cavities, commonly intermixed with more or less earthy material and other salts. It is a glassy or translucent salt, white or stained by impurities. It crystallizes in the monoclinic system, fibrous or columnar massive. It has one perfect cleavage. Its hardness is 2.5 to 3 and its specific gravity about 2.15 in specimens of naturally deposited crystals from Owens Lake examined by Chatard. It appears to be permanent in dry air, is very soluble in water, and effervesces with acids. Its taste is alkaline.

This mineral was shown by Chatard to be among the first of the more soluble constituents to crystallize on concentration of such saline solutions as the waters of Owens and Mono lakes. In the lower part of the main deposit at Searles Lake it occurs as a yellowish caked granular mass, always saturated with the dense mother-liquor brine.

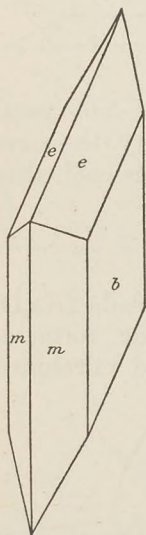


FIGURE 80.—Natron.

## NATRON.

Decahydrated sodium carbonate, or natron ( $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ ; soda ( $\text{Na}_2\text{O}$ ) 21.69, carbon dioxide ( $\text{CO}_2$ ) 15.37, water ( $\text{H}_2\text{O}$ ) 62.94), is the ordinary crystal soda of commerce. It forms transparent colorless crystals, as clear as water, of the monoclinic system.

(See fig. 80.) It has one good cleavage and another less perfect. According to Thorpe,<sup>1</sup> it crystallizes only at temperatures below  $20^\circ \text{C}$ ., and thus only under exceptional conditions is it likely to be found in the soda lakes of desert regions, and if formed and exposed it would soon effloresce into the monohydrate ( $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$ ) known as thermonatrite. It liquefies at  $34^\circ \text{C}$ .<sup>2</sup> in its water of crystallization, secreting monohydrated salt and leaving a liquid portion containing over 10 molecules of water, and again solidifying when the temperature is reduced to  $33\frac{1}{2}^\circ \text{C}$ . It effloresces quickly in the air and so does not naturally occur in crystal form except as immersed in saturated solutions. Its specific gravity has been variously determined as 1.423 to 1.475. Its taste is strongly alkaline.

<sup>1</sup> Thorpe, E., A dictionary of applied chemistry, vol. 3, p. 662, 1912.

<sup>2</sup> Lunge, George, Sulphuric acid and alkali, vol. 2, pt. 1, p. 47, 1909.



As stated by Chatard, sodium carbonate is most soluble in pure water at  $32.5^{\circ}\text{C}$ ., the solution then containing 59 parts  $\text{Na}_2\text{CO}_3$  to 100 parts water. Hence a solution which has deposited crystals at the boiling point redissolves them while cooling till the temperature sinks below  $32.5^{\circ}\text{C}$ ., when recrystallization begins. The solubility varies greatly with the temperature; thus at  $15.5^{\circ}\text{C}$ . the saturated solution contains 14.53 per cent, at  $31.3^{\circ}\text{C}$ . 30.04 per cent, and at  $32^{\circ}\text{C}$ . 31.78 per cent.

#### BORAX.

Borax, the sodium tetraborate ( $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ ; boron trioxide ( $\text{B}_2\text{O}_3$ ) 36.6, soda ( $\text{Na}_2\text{O}$ ) 16.2, water ( $\text{H}_2\text{O}$ ) 47.2), occurs in crystalline form in the Searles Lake deposits, having been extensively worked from the saline crusts in the marshy deposits about the margins of the flat. Borax or some similar compound of boron is also one of the more important constituents of the brine. It has been obtained in drilling as isolated and completely terminated crystals, some of them associated with the crystallized hanksite. It forms in large transparent monoclinic prisms, with truncated lateral edges. The crystals effloresce to an opaque white on the surface when brought into the air but retain their form. Borax crystallizes in the monoclinic system. It has one perfect cleavage and others less distinct, is rather brittle, and has conchoidal fracture. Its hardness is 2 to 2.5 and its specific gravity 1.7. It is soluble in water, especially in hot water, which dissolves double its weight of the salt. It has a sweetish cooling alkaline taste.

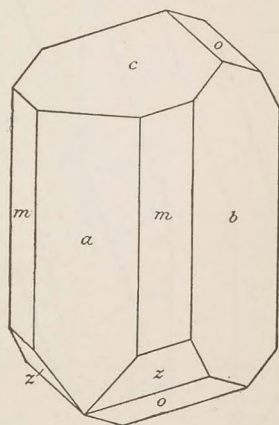


FIGURE 81.—Borax, natural or prismatic form, from Searles Lake, Cal.

Borax forms artificially two varieties of crystals—(1) ordinary or prismatic borax (fig. 81), the decahydrate which is produced by allowing solutions of borax to crystallize by cooling down to the ordinary temperature; (2) octahedral borax, a pentahydrate that separates when a solution crystallizes above  $50^{\circ}\text{C}$ .

#### GYPSUM.

Gypsum, or hydrous calcium sulphate ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ; sulphur trioxide ( $\text{SO}_3$ ) 46.6, lime ( $\text{CaO}$ ) 32.5, water ( $\text{H}_2\text{O}$ ) 20.9), is a common product of desiccation in playa deposits. In its crystalline form (selenite) it is colorless, transparent, often in distinct crystals and aggregates (fig. 82), with very perfect cleavage yielding thin polished folia. Its hardness is 1.5 to 2; and its specific gravity 2.3. It occurs also in fibrous and in massive, fine-grained form, grading into fine



earthy deposits mixed with more or less clay (gypsite). It is soluble in hydrochloric acid and 1 part will dissolve in 400 or 500 parts of water. Van't Hoff and Meyerhoffer have shown<sup>1</sup> that the solubility of gypsum gradually increases with rise of temperature from about 0.18 per cent at 0° C. to a maximum of about 0.21 per cent at about 40° C. With further increase in temperature the solubility steadily decreases until at 100° C. it is again 0.18 per cent, or about the same as it was in ice water. The solubility may be increased more than three times by the addition of sodium chloride and more than four times by the addition of magnesium chloride; this increase is explained in part at least by a reaction which produces calcium chloride and at the same time a sulphate of sodium or magnesium.

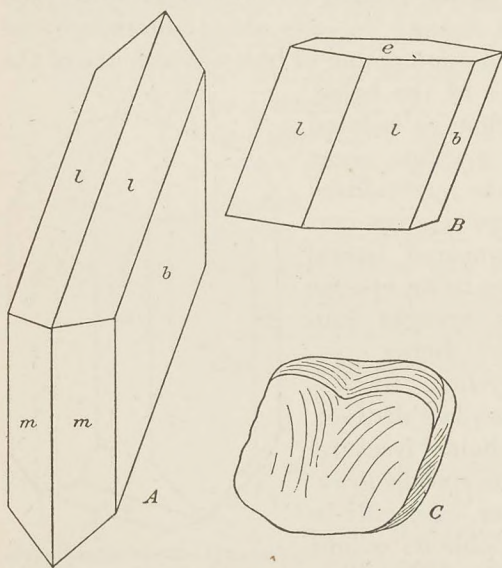


FIGURE 82.—Gypsum (selenite), drawing and sketch from playa-deposited gypsum. The crystal form of C is shown by B.

In summary the authors cited state that there are but two forms of calcium sulphate which are stable in the presence of any solution—gypsum and natural anhydrite—and the stability of one or the other form depends on the temperature and nature of the solution with which it is in contact. For a calcium sulphate solution the inversion temperature is about 66°, and for a saturated sodium solution it is 30°, the presence of other salts tending to depress the inversion temperature. In pure solution gypsum is

stable only up to 66°, when it begins to be transformed into anhydrite, but as the change takes place slowly the solubility may be determined beyond the point of its stability.

#### ANHYDRITE.

Anhydrous calcium sulphate or anhydrite ( $\text{CaSO}_4$ ; sulphur trioxide ( $\text{SO}_3$ ) 58.8, lime ( $\text{CaO}$ ) 41.2) rarely occurs in the form of crystals. It is usually white unless mixed with impurity, massive, cleavable, fibrous, lamellar, granular, and sometimes impalpable. It has three good cleavages in rectangular directions, a property by which it may be distinguished. It is brittle and has an uneven fracture. Its

<sup>1</sup> See summary by Cameron, F. K., and Bell, J. M., Calcium sulphate in aqueous solutions: U. S. Dept. Agr. Bur. Soils Bull. 33, pp. 9 et seq., 1906.



hardness is 3 to 3.5 (harder than gypsum) and its specific gravity 2.9 to 3.0. It is soluble in hydrochloric acid but very slightly soluble in water.

Anhydrite is found generally in deep-seated deposits associated with other salines, but in places where it is protected from the action of moist air. As stated in the section on gypsum, however, it is presumed that anhydrite must have been laid down in such deposits from solutions of rather high concentration of the more soluble salts, as gypsum would ordinarily separate if the solutions were dilute. At or near the surface, in contact with air and moisture, anhydrite is always associated with gypsum, into which it is gradually converted.

#### GLAUBERITE.

Glauberite ( $\text{Na}_2\text{SO}_4 \cdot \text{CaSO}_4$ ; sulphur trioxide ( $\text{SO}_3$ ) 57.6, lime ( $\text{CaO}$ ) 20.1, soda ( $\text{Na}_2\text{O}$ ) 22.3) occurs commonly in playa mud deposits in the form of transparent colorless crystals, in thin rhomboids (of plowshare shape) ranging from half an inch to an inch or more in length. It also occurs in more or less massive aggregates of thin rhombic crystals intergrown. (See fig. 83.) It crystallizes in the monoclinic system. It is brittle, with one perfect cleavage, and has a conchoidal fracture. Its hardness is 2.5 to 3; its specific gravity 2.7 to 2.85. It is soluble in hydrochloric acid. In water it loses its transparency and is partly dissolved, the crystal becoming coated with white calcium sulphate. It has a faintly saline taste.

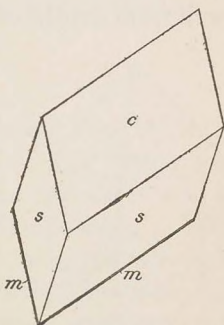


FIGURE 83.—Glauberite from Saline Valley, Cal.

This mineral was described by Blake<sup>1</sup> as occurring in Verde Valley, Ariz., embedded in compact green clay in crystal form evidently resembling that observed in other saline playa deposits. Good specimens of the crystallized mineral were found embedded in the clays underneath the surface-salt crust in Saline Valley, Cal.,<sup>2</sup> and both large and small distinct idiomorphic crystals have been found in the drill samples obtained at various depths down to 100 feet in the Geological Survey boring in Death Valley, Cal., where the crystals were likewise embedded in moist, heavily saline muds.

<sup>1</sup> Blake, W. P., *Am. Jour. Sci.*, 3d ser., vol. 39, p. 14, 1890.

<sup>2</sup> Acknowledgment is due to Mr. Earl Patterson, of Bishop, Cal., for specimens of glauberite from Saline Valley.



HANKSITE.<sup>1</sup>

Hanksite ( $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{KCl}$ ; sodium sulphate ( $\text{Na}_2\text{SO}_4$ ) 81.7, sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) 13.5, potassium chloride (KCl) 4.8) was first identified in 1885 by W. E. Hidden in collections from Searles Lake, where it is found in large amounts, chiefly in isolated crystals, commonly of quartzoid form, although found also in flattened tabloids. (See fig. 84.)

The mineral is clear, transparent, and almost colorless, inclining to a more or less decided yellow, but often clouded by impurity. It crystallizes in the hexagonal system. It has one distinct cleavage and is brittle, with uneven fracture. Its hardness is 3 to 3.5; its specific gravity, 2.55. It is readily soluble in water, effervesces with acid, and has a strongly alkaline taste.

Hanksite was originally found embedded in the soft muds about the margin of the marsh and was noted in the records of the deep well from depths of 2 to 6 feet, 14 to 22 feet, and 50 to 70 feet. Subse-

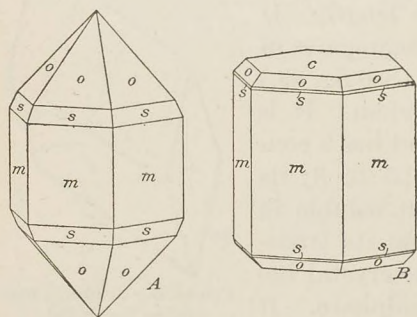


FIGURE 84.—Hanksite from Searles Lake, Cal.

quent drilling in the main salt deposit has developed a zone or layer of hanksite probably extending throughout the deposit at depths of 25 to 30 or 35 feet. This bed varies considerably but is very commonly 5 feet or more in thickness and seems to be composed chiefly of beautifully distinct double-ended hexagonal prisms and pyramids, which much resemble quartz crystals in form.

They range in size from minute grains of perfectly developed form to crystals several inches in length.

NORTHUPITE.<sup>2</sup>

Northupite ( $\text{MgCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot \text{NaCl}$ ; magnesium carbonate ( $\text{MgCO}_3$ ) 33.9, sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) 42.6, sodium chloride (NaCl) 23.5) has been found only among materials brought from the deep well at Searles Lake, where it was reported as occurring in a stratum of clay encountered at a depth of about 450 feet. It is colorless, transparent or glassy when pure, but often clouded by impurities. It apparently suffers no decomposition on exposure to the air. Except for two crystals attached to pirssonite, northupite has been observed only in

<sup>1</sup> Hidden, W. E., *Am. Jour. Sci.*, 3d ser., vol. 30, p. 133, 1885. Dana, E. S., and Penfield, S. L., *idem*, p. 136. Hanks, H. G., *idem*, vol. 37, p. 63, 1889. De Groot, H., *California State Min. Bur. Tenth Ann. Rept.*, p. 534, 1890. Pratt, J. H., *Am. Jour. Sci.*, 4th ser., vol. 2, p. 133, 1896.

<sup>2</sup> Foote, W. M., *Acad. Nat. Sci. Philadelphia Proc.*, Sept., 1895; *Am. Jour. Sci.*, 3d ser., vol. 50, p. 480, 1895. Pratt, J. H., *Am. Jour. Sci.*, 4th ser., vol. 2, p. 123, 1896.



detached crystals. It crystallizes in the isometric system, the octahedron being the only form observed. (See fig. 85.)

The crystals are small, being from less than a millimeter to nearly a centimeter in diameter. There is no apparent cleavage. The crystals are extremely brittle and show conchoidal fracture. Its hardness is 3.5 to 4; its specific gravity, 2.38. It is very slightly soluble in cold water, although rapidly decomposed by hot water, with separation of magnesium carbonate, and it is easily soluble and effervesces in dilute hydrochloric acid.

This mineral was discovered by C. H. Northup in material from the deep well at Searles Lake, which is described on another page. Small crystals were obtained by painstaking search of the "tailings" or débris thrown out from the boring.

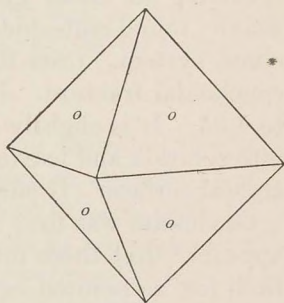


FIGURE 85.—Northupite from Searles Lake, Cal.

#### PIRSSONITE.<sup>1</sup>

Pirssonite ( $\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$ ; calcium carbonate ( $\text{CaCO}_3$ ) 41.3, sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) 43.8, water ( $\text{H}_2\text{O}$ ) 14.9) was first recognized among some crystals of gaylussite found in the deep well at Searles Lake, and has been reported only from that locality. With the exception of two crystals which were attached to northupite crystals, pirssonite was at first observed only in detached crystals. It has, however, been found among the well samples in fragmental form, presumably having been pounded up by the drill, and also in a massive aggregate acting as a sort of cement in more or less consolidated muddy layers of the deposit. The mineral crystallizes color-

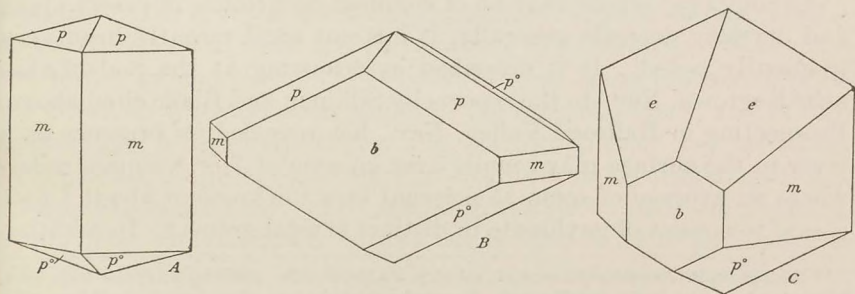


FIGURE 86.—Pirssonite from Searles Lake, Cal.

less, transparent or darkened by impurities, in the orthorhombic system and is hemimorphic in its development. (See fig. 86.) It is extremely brittle, having conchoidal fracture with no apparent cleavage. Its hardness is 3 to 3.5 and its specific gravity 2.35.

<sup>1</sup> Pratt, J. H., *Am. Jour. Sci.*, 4th ser., vol. 2, p. 126, 1896.



GAYLUSSITE.<sup>1</sup>

Gaylussite, a hydrous carbonate of calcium and sodium ( $\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 5\text{H}_2\text{O}$ ; calcium carbonate ( $\text{CaCO}_3$ ) 33.8, sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) 35.8, water ( $\text{H}_2\text{O}$ ) 30.4), is a colorless transparent mineral occurring in small glassy crystals, many clouded by impurities, usually found embedded in mud or clay. It crystallizes in the monoclinic system. (See fig. 87.) It has one perfect cleavage and a conchoidal fracture. Its hardness is 2 to 3; its specific gravity 1.9 to 1.95. It is slightly soluble in water, the sodium carbonate going into solution and leaving a white coating of calcium carbonate on the crystal surface. It effervesces briskly with acids.

Gaylussite was first reported from Searles Lake by Hanks,<sup>2</sup> but it appears<sup>3</sup> that there must have been some mistake in his identification, for, as pointed out by Pirsson, the reactions which he ascribed to the mineral are impossible for gaylussite. All the authentic

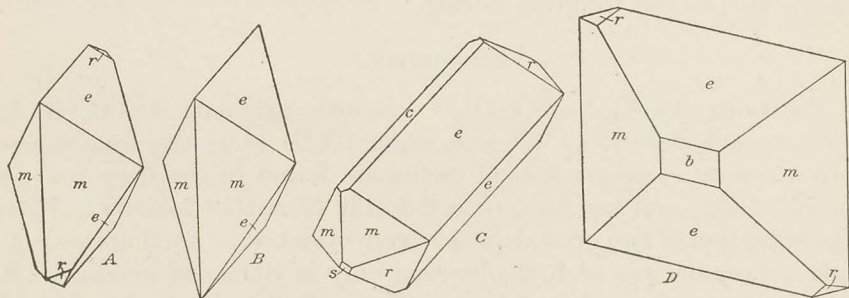


FIGURE 87.—Gaylussite.

specimens of gaylussite from Searles Lake have been distinct crystals, with sharp idiomorphic outline.

Although gaylussite may be of common occurrence in desert playa and dry-lake deposits generally, it has not until recently been very frequently noted. It is described as occurring at the Soda Lakes near Ragtown, Nev., in the reports by Silliman and Blake cited above. Prospecting in Railroad Valley, Nev., has revealed its presence as a layer in the surface playa muds over an area of 7 or 8 square miles, where an average of some 25 per cent in a thickness of about 1 foot is said to consist of gaylussite in distinct crystal grains.<sup>4</sup> In addition

<sup>1</sup> Boussingault, M., *Annales chim. et phys.*, vol. 31, p. 270, March, 1826. Phillips, W., *Philos. Mag.*, vol. 1, p. 263, London, April, 1827. Des Cloizeaux, A., *Annales chim. et phys.*, 3d ser., vol. 7, p. 489, 1843. Des Cloizeaux, A., *Annales des mines*, 5th ser., vol. 14, p. 400, 1858. Fritzsche, J., *Jour. prakt. chemie*, vol. 93, p. 339, 1864. Silliman, B., *Am. Jour. Sci.*, 2d ser., vol. 42, p. 220, 1866. Blake, W. P., *idem*, p. 221. Des Cloizeaux, A., *Manuel de minéralogie*, vol. 2, p. 171, 1874. Arzruni, A., *Zeitschr. Kryst. Min.*, vol. 6, p. 24, 1882. Rammelsberg, C. F., *Jour. prakt. Chemie*, vol. 35, p. 106, 1887. Pratt, J. H., *Am. Jour. Sci.*, 4th ser., vol. 2, p. 130, 1896.

<sup>2</sup> Hanks, H. G., *Gaylussite, on a new variety from San Bernardino County, Cal.*: *Min. and Sci. Press*, vol. 64, p. 222, Mar. 26, 1892.

<sup>3</sup> Pratt, J. H., *loc. cit.*

<sup>4</sup> Report of the Railroad Valley Co.



large buried deposits of this mineral at depths below 700 feet have been revealed by drilling, most of the mineral recovered having the distinct and individual isolated crystal form. It has also been found under similar conditions at other places, as in Dixie Valley and Columbus Marsh, Nev. The accompanying figures show forms obtained from the borings in Railroad Valley, representing each of the crystals figured by Pratt as obtained from the deep well at Searles Lake.

SULPHOHALITE.<sup>1</sup>

Sulphohalite, a sodium sulphate, chloride, and fluoride ( $2\text{Na}_2\text{SO}_4 \cdot \text{NaCl} \cdot \text{NaF}$ ; sodium sulphate ( $\text{Na}_2\text{SO}_4$ ) 73.9, sodium chloride ( $\text{NaCl}$ ) 15.2, sodium fluoride ( $\text{NaF}$ ) 10.9), a transparent mineral with faint greenish-yellow color, occurs in distinct crystals in association with hanksite at Searles Lake. Besides the two mentioned below, only four specimens of this mineral are known, and all are from the same locality. They were found in the Searles deep well at a depth of 35

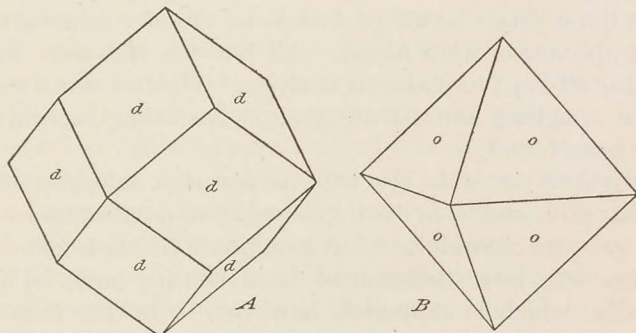


FIGURE 88.—Sulphohalite from Searles Lake, Cal.

feet, where they were associated with a considerable quantity of hanksite. The crystals are isometric, simple rhombic dodecahedrons and octahedrons in form, with a tendency to hemihedrism where the two forms are combined, the octahedral faces being present only on the alternate trihedral solid angles of the dodecahedrons, and of distinct shape, with sharp angles and smooth-polished crystal faces. (See fig. 88.) The crystals vary in size from 0.5 centimeters to 2.5 centimeters in diameter. The specific gravity is 2.5 and the hardness about 3.5. The mineral is very slowly soluble in water and remains unaltered in a moderately dry atmosphere. The occurrence of fluorine is notable in the series of saline minerals deposited from concentrated lake waters, fluorine, like borax, being generally considered an index of fumarole or solfataric action.

<sup>1</sup> Mackintosh, J. B., *Am. Jour. Sci.*, 3d ser., vol. 36, p. 463, 1888. Hidden, W. E., *idem*, vol. 41, p. 438, 1891. Twelvetreves, W. H., *idem*, 4th ser., vol. 6, p. 511, 1898. Penfield, S. L., *idem*, vol. 9, p. 425, 1900. Gale, H. S., and Hicks, W. B., *idem*, vol. 38, p. 273, 1914.



Originally only rhombic dodecahedrons were described for this mineral, but lately two almost perfect octahedrons noted by the writer among some hanksite crystals in a collection belonging to Dr. S. P. Sadtler, of Philadelphia, were subjected to analysis and proved to be sulphohalite.

#### TYCHITE.<sup>1</sup>

Tychite ( $2\text{MgCO}_3 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{Na}_2\text{SO}_4$ ; magnesium carbonate ( $\text{MgCO}_3$ ) 32.3, sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) 40.5, sodium sulphate ( $\text{Na}_2\text{SO}_4$ ) 27.2) was discovered by the merest chance in 1895, when some northupite crystals from Searles Lake were being studied in the mineralogic laboratory of the Sheffield Scientific School at New Haven, Conn. A single very small specimen, which happened to be the first of a lot selected from among a large number of octahedral crystals for chemical test, was found to differ in composition from what had been expected and was thereupon identified as an entirely new species. Out of fully 5,000 specimens examined the very first crystal and one of the last ten crystals tested proved to be the new mineral and only two other specimens were found. All but the last were lost in an unsuccessful attempt to make an analysis. The last was a very small octahedron weighing but 0.0109 gram. No other natural crystals have ever been found.

The individual crystals are transparent and colorless, effervesce readily with acid, and were distinguished from northupite by the fact that they gave no chloride test but a sulphate reaction instead. The composition was later determined from similar material prepared synthetically, which is supposed, however, to be the true mineral. Its specific gravity is about 2.45; its hardness about 3.5 to 4. It is almost insoluble, even in hot water. It crystallizes in the isometric system in octahedrons.

#### SEARLESITE.<sup>2</sup>

Searlesite, a hydrous sodium borosilicate ( $\text{Na}_2\text{O} \cdot \text{B}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ ), in spherulites of radiating fibers, was found embedded in the muds in the Searles deep well at a depth of 540 feet. It is colorless or white. It is soft and its gravity has not been determined on account of lack of material. It is intimately associated with calcite and less intimately with pirssonite. It may prove of particular interest if found more abundant, as it contains theoretically about 17.15 per cent of boric acid.

<sup>1</sup> Penfield, S. L., and Jamieson, G. S., *Am. Jour. Sci.*, 4th ser., vol. 20, p. 217, 1905.

<sup>2</sup> Larsen, E. S., and Hicks, W. B., *idem*, vol. 38, p. 437, 1914.



## HISTORY OF THE SEARLES LAKE DEPOSITS.

According to De Groot <sup>1</sup>—

This extensive and valuable deposit of borax was discovered by John W. Searles, who first observed signs of this salt when crossing the marsh that now bears his name, in 1862, at which time he was engaged in prospecting for gold in the Slate Range, lying to the east. Being unacquainted with the nature of the substance, he did not at the time pay much attention to it. Afterward, however, when borax began to be an object of general inquiry, he recognized in some samples of this salt shown him the stuff he had noticed while crossing this alkaline flat several years before. Satisfied on this point, he at once took proper steps for locating such portions of the marsh as he considered most valuable.

The deposit is reported to have been located by J. W. Searles and E. M. Skillings on February 14, 1873. Borax was then obtained from the surface scrapings over the mud deposits about the margin of the main salt area, operations which have already been referred to.

Probably the first to suggest that potash might become one of the profitable products of this deposit was Whitman Symmes, who in 1898 was superintendent of the California Borax Co., operating at Searles Lake. Mr. Symmes is said to have at that time located nearly the whole of the salt area of this deposit with the object of working the brine for the extraction of its borax, soda, and potash. The enterprise did not find sufficient support and was allowed to lapse.

In 1908 the whole deposit (41,200 acres, or about 65 square miles) was again located and subsequently was relocated by C. E. Dolbear and seven others for the purpose of establishing there a carbonate of soda or "soda ash" industry. An extensive plant was put in, but for one reason or another the whole equipment was allowed to become idle before any of the soda was shipped.

The announcement of Searles Lake as a possible source of potash, which directed public attention throughout the country to the deposit, was made in a joint press bulletin issued by the United States Geological Survey and the Bureau of Soils soon after the first telegraphic press reports late in March, 1912. This announcement is quoted in full as follows:

POTASH IN "BORAX LAKE"—ANCIENT LAKE BED IN MOHAVE DESERT OF SOUTHERN CALIFORNIA MAY FURNISH MILLIONS OF TONS.

The two Federal bureaus engaged in the search for potash—the Bureau of Soils of the Department of Agriculture and the Geological Survey of the Department of the Interior—are in receipt of promising telegraphic news from their field representatives. A potash deposit of apparently great importance has been discovered at Borax or Searles Lake, in the northwestern corner of San Bernardino County, Cal. This lake or playa is the last remaining pocket of a once much greater lake which has almost dried up, and its central depression contains a large body of crystalline salts known to consist of common salt and sulphate and carbonate of soda with smaller quantities of borax. This salt body is saturated with brine, and interested persons stimulated by the

<sup>1</sup> De Groot, H., The Searles borax marsh, California; California State Min. Bur. Tenth Ann. Rept., pp. 534-539, 1890.



governmental search for potash recently secured an analysis of old sample material from this brine. The result being significant, the lake was visited jointly by representatives of the Geological Survey and of the Bureau of Soils, who took brine samples from six wells distributed over the salt flat. Analyses of these samples have been made by the cooperative laboratory at the Mackay School of Mines, at Reno, Nev., and show an average of 6.78 per cent of potassium oxide ( $K_2O$ ) in solution. The average salinity of the brine is 43.82 grams of solids per 100 cubic centimeters. Comparison of the results indicates that the brines are nearly uniform throughout the flat. The probable importance of the deposit is due to the occurrence of the potassium salts in soluble form in a natural saturated brine and under climatic and other conditions especially favorable to its separation and recovery by solar evaporation. Existing data give reasonable assurance that the brine-saturated salt body is at least 60 feet thick and covers an area of at least 11 square miles. Assuming the salt body to contain 25 per cent by volume of the brine, the total amount of potassium oxide is estimated at over 4,000,000 short tons. This estimate is believed to be very conservative and the available tonnage may well be expected to exceed 10,000,000 tons, which would supply the country, at the present rate of consumption of potash, for 30 years. At any rate it appears that this locality constitutes a very important source of potash in probably readily available commercial form.

Methods of separating potash from brines are now under investigation by the Bureau of Soils.

This statement was based on the evidence from analyses of a representative set of brine samples collected jointly from the main deposit early in March by E. E. Free, then of the Bureau of Soils, and the writer. Shortly before the making of this announcement a report had been received that an attempt to exploit the deposit as a source of potash was being made on the basis of three analyses that had been made for this purpose not long before by a firm of private chemists. The materials from which these analyses were made were some sample residues that had been kept from a previous investigation of this deposit with special reference to soda and borax. The three analyses were in effect an afterthought, being made in response to a suggestion concerning a possible potash value in the deposit, which came after the original work on the samples had been completed. Only one of these analyses (the one quoted on p. 311) showed an apparently significant amount of potash. One analysis of this set has already been quoted (p. 294); the other two are as follows:

*Early analyses to show potash content of Searles deposits.*

Salts.	
Insoluble in water.....	1.44
Sodium chloride ( $NaCl$ ).....	45.90
Sodium sulphate ( $Na_2SO_4$ ).....	22.80
Sodium carbonate, anhydrous ( $Na_2CO_3$ ).....	16.57
Sodium bicarbonate ( $NaHCO_3$ ).....	6.50
Sodium baborate, anhydrous ( $Na_2B_4O_7$ ).....	2.32
Potassium chloride ( $KCl$ ).....	3.64
	<hr/>
	99.17



## Brines.

[Specific gravity, 1.300 at 23° C.]

	Grams per 1,000 cubic centimeters.	Per cent in original sample.
Insoluble in water.....	262	20. 15
Sodium sulphate, anhydrous ( $\text{Na}_2\text{SO}_4$ ).....	71	5. 46
Sodium carbonate, anhydrous ( $\text{Na}_2\text{CO}_3$ ).....	60	4. 62
Sodium bicarbonate.....	Trace.	. 00
Sodium baborate, anhydrous ( $\text{Na}_2\text{B}_4\text{O}_7$ ).....	17. 2	1. 32
Potassium chloride.....	( <sup>1</sup> )	4. 50
		36. 05

The analysis of the salts was made on a composite sample, an average of the salts obtained from borings in the deposit, but exclusive of material from the uppermost 20 feet. The brine analysis was made on a similar composite of all samples of the well waters then on hand. These analyses are only partial, as that of the brine fails to report the sodium chloride, which is the principal constituent, but the potassium reported corresponds approximately with the results that have subsequently been obtained on other samples. The analyses are quoted here mainly for their historical interest.

Although undue emphasis should not be placed on the fact that the Government agents who examined the deposit thus issued the first public announcement of the deposit as a likely source of commercial potash, nevertheless it is only proper to make clear the circumstances under which these events took place. Only a very few potash analyses from this deposit, made by private persons, showing in any way a potash content in the brines or salts of this deposit were at that time extant. Some apparently extravagant statements had previously been issued, based on what was deemed by many to be insufficient information, the results of a single analysis. In view of this skepticism the Government tests were made and the single potash determination of one of the first of the private tests referred to was substantially confirmed. The announcement quoted above was the first favorable opinion as to any desert-basin saline deposit that had yet been examined in the course of the general field investigation by the Government. This favorable opinion was based mainly on the fact that this basin seemed to fulfill almost entirely the conditions of the hypothesis for the formation of the desert-basin salines on which the field explorations by the Geological Survey had been based.

## PROSPECTIVE COMMERCIAL DEVELOPMENT.

The prospective development of the Searles Lake deposits is naturally a matter of considerable interest as an enterprise without precedent in this country. According to late advices <sup>2</sup> construction on the new

<sup>1</sup> Quoted as 36.9 grams  $\text{K}_2\text{O}$  in 1,000 cubic centimeters original solution, or 5.84 per cent KCl.

<sup>2</sup> Eng. and Min. Jour., vol. 97, No. 9, p. 484, Feb. 28, 1914.



experimental unit in which the American Trona Corporation will begin the manufacture of potassium chloride and other salts from the brine of Searles Lake is progressing. The 31-mile railroad from Searles, on the Southern Pacific Railroad, to the new town of Trona, where the works are being built, is nearly completed. The preliminary plant, it is reported, will handle 20,000 gallons of brine daily, and when the process and equipment have been thoroughly proved by actual operation the works will be enlarged. The salts from the Searles Lake deposit, it is stated, probably will not enter the market regularly until late in 1914. In the meantime a very large number of borings have been sunk through the deposit. This work is intended to serve the purposes of assessment or patent requirements on the claims and to prove the extent and nature of the deposits in depth and areally.

Such an undertaking is primarily a chemical manufacturing enterprise, whose success will depend on the utilization of all advantages or economies to be gained by large-scale production and the use or sale of all possible by-products, as well as on the skill developed in handling the physical and chemical problems involved in the separation of the salts. The commodities to be produced are already being supplied in the market, and it is expected that competition for a place in the industry will be keen. The products are bulky and relatively lowpriced, so that they will suffer the disadvantages of heavy transportation charges in order to reach many of the important markets of the country. Moreover, the initial investment for such an operation is necessarily heavy.

### PANAMINT VALLEY.

#### THE FORMER LAKE.

While the waters in the Searles Basin stood at their highest level they undoubtedly overflowed by way of the pass at the south end of that basin and entered the larger and deeper basin of the Panamint Valley. Here they formed the principal water supply of a lake which of course received also contributions of the desert drainage tributary to its valley. This immense body of water, having an origin similar to that of Searles Lake, may have produced in the Panamint Valley saline deposits resembling those in the Searles Basin, but there are many qualifying factors to be considered in offering judgment as to whether this is or is not the case.

Panamint Lake was 60 miles in length from north to south and 5 or 6 miles wide for the greater part of its length, though nearly 10 miles wide in the broader portion of the valley north of Ballarat. It was of a different form from the lake in the Searles Basin, being confined in a long, relatively narrow and deep basin, whereas Searles Lake occupied a broad oval basin. Panamint Lake narrowed to a



point at its south end, and this was not only the point of inlet for the overflow from the Searles Basin but it appears that the inlet was also near the position of its probable outlet or overflow during the period of its maximum flooding. The greatest depth of Panamint Lake was probably determined by Wingate Pass, through which an overflow is believed to have passed for some time into Death Valley. The feature of this outlet was not at first recognized but has been brought to attention with the completion of topographic mapping about the south end of the Panamint Basin. It is also a feature that deserves further study on the ground, as it offers a possibility of developing even more of the historical record of this drainage system, which certainly has not before been fully interpreted. The area of Panamint Lake at its various water levels is indicated by the following planimeter measurements obtained from the topographic map:

*Area of former Panamint Lake at different levels.*

Elevation of water level.	Area.
<i>Feet.</i>	<i>Square miles.</i>
1,977	272.55
1,900	252.20
1,800	221.48
1,700	189.88
1,600	141.32
1,500	129.02
1,400	110.03
1,300	93.21
1,200	74.89
1,100	54.10
1,045	19.32

At its uppermost recorded elevation the water stood 930 feet above the present valley bottom opposite Ballarat. The original lake was doubtless considerably deeper, the basin having been subsequently filled by inwashed sediment, but as yet little can be said as to the depth of this filling.

Calculations of the volume of the ancient lake at its various levels are given in the following table. These are based on application of the prismoidal formula to horizontal sections of the present basin, as was done in the computations on the Searles Basin.

*Calculated volume of former Panamint Lake basin.*

Inclusive contours.	Depth of section.	Volume.
<i>Feet.</i>	<i>Feet.</i>	<i>Acre-feet.</i>
1,977-1,900	77	12,927,000
1,900-1,800	100	15,147,000
1,800-1,700	100	13,151,000
1,700-1,600	100	10,560,000
1,600-1,500	100	8,648,000
1,500-1,400	100	7,642,000
1,400-1,300	100	6,496,000
1,300-1,200	100	5,369,000
1,200-1,100	100	4,110,000
1,100-1,045	55	1,241,000
		85,291,000



Evaporation during the maximum flood stage, as well as inflow and evaporation within the basin during receding stages of the lake waters, when the lake could have had no outlet, may have greatly increased the total volume of waters that were eventually evaporated within the basin. Panamint Lake is apparently analogous to Searles Lake, as each lake received its waters by overflow from a higher basin and each at some stage undoubtedly overflowed to a lower basin.

The evidence at hand concerning the existence of the ancient lake in the Panamint Basin is briefly as follows:

East or southeast of the old town of Ballarat on both sides of the mouth of Pleasant Canyon is an immense boulder delta of material evidently derived as wash from the adjacent mountain slopes and carried out by way of the drainage channels. This delta is flat-topped and abruptly truncated on the valley side, a peculiar relation which first attracted attention to it as a probable delta deposit formed under standing water. The normal alluvial deposit formed under subaerial conditions is of course a graded slope extending for a greater or less distance into the valley. The abrupt truncation of such deposits might be explained by differential offsets due to recent fault movement, but the idea that first presented itself was that this coarse alluvial material was thrown down by torrential floodwaters when they were checked by meeting the standing water. This idea appealed to Campbell,<sup>1</sup> who probably was the first to record the existence of a late Quaternary lake in this basin. Campbell described the immense boulder deltas at the mouth of Wild Rose Canyon and above Ballarat as evidently deposited in a body of standing water. Judging from the slope of the boulder surfaces, he expressed the conclusion that there had been rather profound warping or faulting in the region since the lake period. This may be true concerning a preceding glacial-lake history (see p. 320) not yet definitely established, but as regards the present most evident succession of old lake-shore benches the determinations of elevation from point to point about the basin have not yet shown any great amount of displacement.

The gravel ridges back of Ballarat have none of the internal structure of typical deltas. When flowing water enters a body of standing water its load of coarse material is normally carried forward with the current until the water loses its motion by mingling with the deeper waters, when the suspended load sinks, being deposited in layers with marked inclination toward the deeper parts of the basin. As the delta is built out the surface is extended with a thinner section of relatively horizontal layers, but the advance at the front consists of the deposition of inclined beds, in a way analogous to the building

<sup>1</sup> Campbell, M. R., Reconnaissance of the borax deposits of Death Valley and Mohave Desert: U. S. Geol. Survey Bull. 200, p. 20, 1902.



out of a mine dump where the waste is carried forward in mine cars and emptied over the edge, while a certain portion is spilled along the top. The ridges back of Ballarat show none of these "foreset" features and consequently suggest that they may be portions of the prelacustral valley fill, elevated to their present positions by faulting. There is some other evidence to support this hypothesis. It may be, therefore, that these bars, which were at first taken as evidence of the existence of an ancient lake in this basin, have no direct relation to the lake history of the valley.

However, the evidence of ancient shore markings, including the usual wave-cut terraces, tufa deposits, and characteristic light-greenish saline clays in thin-bedded deposits at certain places about the shores, gives indisputable evidence that such a lake existed and indicates about what its maximum depth must have been.

Some rather unsatisfactory barometer readings for elevation on the slope east of Ballarat up to the level of the upper shore terraces seemed to indicate that the old lake had stood 1,200 or 1,300 feet above the valley. There is some doubt as to the value of this determination, in the face of later evidence. Duplicate barometer readings showed with practical agreement an elevation of 1,950 feet for the lower of two distinct shore benches near the Ballarat-Searles road southwest of Ballarat. An upper bench 20 or 30 feet higher than this is the highest of these terraces recognizable in this part of the valley. One barometer reading on the shore lines east of Ballarat agrees with this determination. On another trip along the whole length of the Panamint Valley to the extreme south end barometer readings with frequent checks on standard bench-mark elevations gave additional evidence. In the southern part of the valley the shore lines are not everywhere easy to recognize. Moreover, a number of the original metal bench-mark posts set in that part of the country had been erroneously marked with an elevation just 100 feet in excess of the actual elevation determined, and this upset the field calculations. The figures given on the Survey topographic map (Searles Lake sheet), however, are the corrected ones. Near Wingate Pass, at an elevation of 1,900 to 1,910 feet in the main Panamint Valley (checked on bench mark 1916 at the forks of the road to Lone Willow) there are thin-bedded horizontal greenish-white marl-like clays, covered in exposure with a white saline efflorescence such as is very characteristic of water-deposited sediment along the tributary inlets of desert lakes elsewhere. If these beds were deposited under water the highest lake level should be looked for still higher (above 1,916 feet). No actual shore traces were observed just here, although doubtless favorable conditions of light might serve to bring them out, but terraces and benches of the same light-greenish clays appear from this point to the north (down the valley) for a consid-



erable distance. The bedding of these deposits shows a slight inclination toward or down the valley. They are believed to be only remnants of much more extensive deposits which have been worn away by erosion. A few miles farther down the valley, about opposite Wingate Pass, the marly clay "lake beds" are conspicuous and contain scattered crystals of selenite. Distinct horizontal shore lines were noted in the slope below Wingate Pass and are assumed to represent stages of greater or less permanence of water level during the recession of the ancient lake. From this point northward down the valley faint but undoubted shore markings of the higher levels show from place to place, peculiar or favorable light serving to bring them out at times with great distinctness. Thus, the lowering sun often casts a shadow over a succession of benches on the west side of the valley, bringing them out with much distinctness. Shore lines were observed above the Redlands mill, on the east side of the valley 9 or 10 miles south of Ballarat, and at various other places. On coming into the town of Ballarat from a northwesterly direction in late evening light, one sees from the center of the mud flat a series of shore-line markings high on the mountain slopes of the east side of the valley, and these extend for a long distance, appearing plainest on the smooth slopes north and south of Pleasant Canyon. These markings are preserved especially well on the steeper slopes of wash *débris*, such as the wash deposits near the mouths of the deeper gulches, but are generally unrecognizable along the greater part of the more rocky slopes about the valley.

The final bit of evidence concerning the maximum water level of the Panamint Lake was found in the contouring and elevations in Wingate Pass, which leads from the Panamint Valley into Death Valley. These data were obtained in recent surveys for maps now in preparation. Wingate Pass has an elevation of 1,977 feet above sea level (the bench-mark post at the summit 10 feet east of the road,  $2\frac{1}{2}$  miles east of the junction of the road in Panamint Valley, standing at 1,976.778 feet). This pass, which is the only possible point of outlet for such a lake, has not yet been visited for the purpose of determining what evidence it may afford as to an overflow into Death Valley, but the coincidence of this elevation with the elevations of upper shore traces in other and distant parts of the valley seems to indicate not only that such an outlet existed for a time at least, but also that subsequent faulting, warping, or tilting in the valley may not have greatly modified the Panamint Lake basin, as was suggested by Campbell.

The various shore levels on the valley margin slopes are more or less conspicuously marked by lake-deposited tufa, a calcareous coating apparently similar to the corresponding deposits in the Lahontan



and Bonneville basins described in detail by Gilbert<sup>1</sup> and Russell.<sup>2</sup> The latest deposit of this material appears as a low reef 8 or 10 feet above the mud flat, especially along the west shore opposite Ballarat. This reef is assumed to have been formed by the deposition of lime from solution in lateral seepage waters which may have entered during a period of shallow submergence of the mud flat to the depth indicated. Much scattered tufa was observed at an elevation of about 1,220 feet (barometric) and at other levels, the highest being at about 1,970 to 1,980 feet, which is, as noted above, the elevation of the probable outlet.

Some clue as to the age of Panamint Lake may be indicated in a collection of fossils obtained from the tufa of the lake-shore deposits at the 1,950-foot level along the Searles-Ballarad road. These were submitted to W. H. Dall, who reports as follows:

I have examined the fossils from the Lahontan Basin and Panamint Valley, referred to in the letter of Hoyt S. Gale dated December 9, 1913. They belong to the characteristic Quaternary fauna of the Great Basin and are of probably the same geologic age. Those from the Panamint Valley comprise the following species:

*Carinifex newberryi* Lea.

*Pompholyx costata* Hemphill.

*Lymnaea utahensis* Call.

*Physa humerosa* Gould.

*Valvata utahensis* Call.

*Amnicola dalli* Call.

*Amnicola cincinnatiensis* (Anth.) Call.

#### GEOLOGIC STRUCTURE OF THE PANAMINT VALLEY.

The structure suggested by the Panamint Valley is that of a down-faulted block or "graben" in which the greatest depression appears to have been on the east side of the valley, as is indicated by the present profile of the valley cross section, the abrupt rock wall of the east contrasting with the broad alluvial slopes reaching into the valley from the west. The hot spring at the north end of the valley and the springs near Ballarat indicate a zone of faulting along this edge of the valley, and the abrupt truncation of the delta deposits near Ballarat may be in part due to faulting before the period of lake occupancy. This might account for the position of the lowest valley depression near the eastern valley margin, and a similar position is suggested for a possible concentration sink in the desiccation of former lake waters. If the topography of Panamint Valley has been greatly modified since the recession of that ancient lake, it seems as if the modification must have been effected by faulting along this line or by the extravasation of alluvial material from the rocky canyons and precipitous slopes of the eastern valley margin. From present appearances it is hard to see how either process has accomplished any specially significant changes.

<sup>1</sup> Gilbert, G. K., Lake Bonneville, U. S. Geol. Survey Mon. 1, 1890.

<sup>2</sup> Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, 1885.



The Warm Springs, at the north end of the mud flats 5 miles north of Ballarat, seem to occupy a local sink in which a small distinct drainage leads toward the springs through minor channels in the playa. This apparent anomaly may be accounted for either wholly or in part by recent fault drop tilting down this edge of the basin, while it is also true that this corner, protected by lying at the very foot of a precipitous rock wall, receives inwash only along the valley from either the north or the south side of this steeper slope and so forms a natural basin in the slope of valley sediments. The crusted salts about this basin have been scraped for local domestic and stock use. A pond of exceedingly briny water occupies the bottom of the depression below the springs.

#### DRILLING IN PANAMINT VALLEY.

Prospecting in the Panamint Valley for buried saline deposits was begun by private interests in November or December, 1913. One or more shallow holes had been sunk earlier in the year, it is supposed with inconclusive results. The more complete exploration of this basin offers a practical test of the hypothesis of buried salts as a result of the desiccation of a Quaternary lake that is known to have evaporated and left only an insignificant deposit on the surface. The possibilities seem to be various, and the result of a complete test is to be watched for with interest.

A saline deposit, if one exists in the Panamint Valley, will doubtless be of much the same type as that of Searles Lake, for it must have been formed chiefly by overflow of the waters that passed through the Searles Basin. As the waters of Searles Lake were supposedly dilute during their higher stages it seems unlikely that much differentiation could have taken place within them, and the overflow to the Panamint Lake was not in the nature of a mother liquor.

In speculation concerning a possible saline deposit in the Panamint Valley two prime questions present themselves, which probably can be answered only by the use of the drill. First, did concentration below the level of overflow go on in this basin for a sufficiently long time for a great mass of salines to have accumulated as in the Searles Basin? Second, if the concentration took place and the salts were deposited on the evaporation of the lake, has the valley been filled to such an extent that the deposits are inaccessible? The only judgment that can be offered in these matters, until they are tested by drilling, is that to be had from the study and interpretation of the records left by the lake waters, such as the evident permanence of former lake levels, the size and importance of inflow and overflow channels, and the amount of modification the basin has undergone since it was occupied by water. These records may indicate probabilities, but as yet they do not seem to be conclusive.



Some quantitative idea of the interpretations to be placed on this lake history may be obtained from the following computations: The water content of the ancient Panamint Lake at its highest level, as has been stated, was approximately 85,000,000 acre-feet. If the concentration of the water at this highest level, necessarily a matter of pure assumption, was 300 parts per million of dissolved salts, or about that of the present flow of Owens River, the total quantity of salts dissolved in this ancient body of water would have been about 35,000,000 short tons of anhydrous salts. This would be equivalent to a layer of the anhydrous salts 20 acres in extent and 1 foot deep, or with some water of crystallization and mother liquor perhaps the same area to a depth of several feet. It will be seen that the single filling and evaporation of a lake like that which formerly existed in the Panamint Valley would not necessarily result in the deposition of a large mass of salts when the lake dried up, but that such a lake must continue to concentrate waters of the character described for a long period in order to produce a very thick deposit of salines. That such a long-continued concentration actually took place in the Searles Basin is very certain, and there seems to be ample possibility that a similar concentration may have occurred in the Panamint Basin, though definite assumption of its occurrence is scarcely warranted.

#### GLACIAL AGE OF FORMER LAKES.

The correlation of the Quaternary lakes of Owens Valley and similar areas in the Great Basin with the stages of ice extension in the glacial epoch rests upon general considerations, although it is accepted by most geologists. The correlation of the maxima of Lake Bonneville and other lakes of the Great Basin with the stages of glaciation is considered at some length in the Bonneville monograph.<sup>1</sup> It is also generally agreed that the evidence of the glacial epoch in the West shows it to have consisted of at least two general stages of ice extension separated by a long period in which glaciation ceased. Since the ice last left the region the effects of weathering and erosion have been trivial, the morainic material of the last stage is but little disintegrated, and the contour of the latest of the glacial deposits has been only slightly altered.

Evidence of duality of the lacustral history in the Owens and related basins has not yet been recorded, but emphasis should be placed on the fact that the studies on which the present statements are based have been only of the most general character, and that much remains to be desired in the way of observation in these fields. By analogy

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<sup>1</sup> Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 265-318, 1890.



with the recorded history of Lakes Bonneville, Lahontan, and Mono some or all of these basins are supposed to have had a dual lacustral history. By continuing the analogy the first of these stages is assumed to have been the longer, and the stage between inundations to have been probably more arid than the present day and several times longer than the second lacustral stage, although the waters may have temporarily risen during the second stage to their highest level. It is stated that the greatest expansion of the waters of the Mono Basin occurred subsequent to the last extension of the Sierra Nevada glaciers. It is reasonable to assume that the other lakes of the Great Basin attained their maxima at the same time.

Whatever may be the true explanation of the glacial epoch in this part of the world, it is perhaps reasonable to assume that it represents a period of somewhat larger precipitation—that is, of greater humidity of climate. The accumulation of immense fields of snow and ice during certain stages of this epoch was undoubtedly followed by stages in which the melting of the snow and ice must have rapidly released very unusual volumes of water. Thus it is natural to suppose that the maxima of lake expansion may have been contemporaneous with or slightly lagging upon the stages of ice retreat, the waters being derived partly from the normal precipitation, but chiefly from the release by melting of the immense storage in the fields of glaciation. This affords an explanation for the apparent localization of the larger Quaternary lakes in the Great Basin, in their relation to the mountains of larger glaciation.

The basins in which these lakes were formed doubtless originated through displacements of the earth's crust in a region of such general aridity of climate that no continuous drainage to the sea has ever been established since they were formed. After the principal diastrophism by which the general configuration of these basins was established, followed a long stage of erosion and alluviation under arid conditions, during which broad delta-form deposits were built out from the mountains and the valley bottoms were filled to an unknown but probably great depth. Toward the close of this stage the lakes rose and filled certain basins, as has been stated, but since the waters have last receded relatively insignificant modification of the topographic forms has taken place. If the lake history of these basins has in fact been dual, as suggested, the question arises, Are the records of both inundations to be observed in the valley basins, or has the earlier record been so nearly obliterated that its traces are difficult to recognize or have not yet been identified?

The lake terraces described, including old high-level beaches and wave-distributed boulder slopes, indicate in all their features the comparative recency of their formation and distribution. Talus of coarser rock fragments, angular and only slightly disintegrated,



lies where it has been laid down by water action, below the upper shores in many parts of these basins, especially on the rocky slopes of the Searles Basin. These angular boulders are piled in insecure positions, so that in places a shove of the foot will upset them and send them down the slopes, and yet in places the unbroken coatings of water-deposited tufa indicate that, as a matter of fact, the rocks have not been disturbed since they were last exposed by the receding lake waters.

The only clues to the supposed earlier and almost entirely obliterated lake record lie in the suggested tracing of shore lines and apparent wave-cut benches in both Searles and Panamint valleys at higher levels than the most distinct shores of the last and most evident stage, either indistinct or, if definite in outline, of forms so rounded as to be difficult of interpretation.

If, then, the conclusion is to be tentatively adopted that present evidences of the glacial lakes may be correlated in time with only the most recent stage of ice advance, as seems very likely, the question naturally arises, What may have been the lake history of this whole system during the earlier glacial stage? As a corollary it is also pertinent to inquire whether there may not also have been during the earlier stage saline deposition at least equal in magnitude to that resulting from the later desiccation.

#### PROSPECTS OF POTASH FROM THE DESERT BASINS.

When general interest was first aroused in the subject of potash in the West, attention was naturally directed to all natural accumulations of soluble salts, including "dry-lake" incrustations, residues or efflorescences, mixed mud and salts, and saline or alkaline lakes or well waters. In the testing of these deposits the public very generally participated. It was clearly impossible at that time to define or predict with certainty what classes of materials were most promising as a source of commercial potash, and there was no standard of comparison as to the percentage of potash necessary in a mixture or compound to make it commercially workable. At first the campaign of general, more or less haphazard, testing was entirely justified.

At the same time, however, the dominant idea in the exploration of the desert basins for saline and potash concentrations depended on the assumption of former saline lakes, whose waters by evaporation must have left their salts as massive saline residues. This idea has been referred to as the desert-basin saline hypothesis. At first it was very generally assumed that such lakes had existed in almost all the inclosed drainage basins, chiefly because these areas were alike in not having any present outlet, and the rise of their waters was supposed to have been due to a prevailing more humid climate. On further consideration, however, it is now believed more likely



that these ancient lakes were not so widely distributed in the desert-basin region as was at first assumed, and it is even probable that large or persistent water bodies of this type were confined to relatively few areas. Therefore saline concentration in the desert basins may have been going on for long periods under intermittent lake or playa conditions, but the accumulation and deposition of salts in thick crystalline masses as a result of the desiccation of major saline lakes has perhaps been of comparatively rare occurrence. On this basis of reasoning random drilling in the desert basins in the search for large salt deposits is probably not justified from present evidence.

A further conclusion as to saline deposits in ancient lake basins seems warranted. The present ordinary lake waters of the region, such as those of Walker, Pyramid, and Winnemucca lakes, represent accumulations and concentration of tributary drainage waters for a very considerable period. In spite of this fact, if these lakes should dry up their total saline content if deposited as a residue on their dry bottoms would not form a very considerable mass of salts. It is therefore evident that the single filling of such lake basins is not evidence of any considerable saline accumulation in its waters, nor is even the existence of a concentrating reservoir through a long period of time very positive evidence of such a concentration. It therefore becomes important in attempting to estimate the chances of saline deposition from a given lake record to take due account of the probable duration of the concentration period, and this is likely to be a difficult factor to estimate.

The question whether potash would be segregated as a result of saline accumulation in shallow intermittent lakes and the resulting formation of lake deposits has also to be considered. It seems a justifiable conclusion that in such lake beds the potash and other salts would generally be so intimately mixed together or with mud or clay as to be a very unlikely source of commercially valuable materials. Before this idea was generally understood "potash" locations were staked in many of the desert playas and saline flats throughout the desert region. These locations were supported by the "discovery" of small percentages of soluble potash in the surface efflorescences or in the ground solutions of the playa deposits. It is now well known that potash is sparingly distributed in almost all natural saline deposits, and that its presence in small amount has therefore no special significance.

Perhaps the most important factor influencing the disposition of the soluble potash contained in natural drainage waters is the power which clays have of absorbing potash when brought into contact with its solution. It appears that herein lies the actual explanation of the apparent disappearance of much of the potassium salts from solutions or from the saline deposits collected in the desert basins.



Although the selective power of clays for absorbing potassium has long been recognized, its influence probably has not been fully appreciated in the discussions of the possible occurrence of potassium salts either in the desert-basin saline deposits or elsewhere in association with other salt deposits. Attention has been repeatedly directed to the low content of potassium as compared with sodium in the desert-basin salines, especially through the many analyses of brines, saline incrustations, and saline muds that have been made during the present investigations. It is significant that certain mud deposits associated with these natural salts have been found to yield unusual amounts of potash, which are not in water-soluble form as obtained in samples, but which readily become soluble on extraction with solutions containing ammonium chloride. The potash appears to be held in the mud either mechanically or in a loosely combined form, and it may have become fixed in this condition by the absorptive action of the muds on the concentrating saline solutions with which they have come into contact.

As a summary, it is probably safe to say that commercially valuable concentrations of potash are not to be looked for in the desert-basin deposits generally. In the first place, salines deposited by shallow intermittent lakes are not only so mixed with muds as to render their profitable recovery very doubtful, but such deposits are unlikely to retain on a large scale any considerable percentages of potassium in the soluble form. Only in the basins where large and deep saline lakes have existed and dried up under favorable conditions are massive deposits of salines free from mixture with mud to be looked for. Such conditions are rather exceptional. Probably few desert saline lakes have in fact dried up so free from the mixture of clay or other sediments that their water-soluble salts have retained the major portion of the potash originally present in the lake water.

The confident hope is still held out that these exceptional conditions exist in some places and that by good fortune or otherwise they may be revealed. It seems that in Searles Lake one such exceptional place has been found, and it is possible that there may be even larger and more valuable deposits still to be discovered.



